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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

EDITED BY

GEORGE E. HALE
Mount Wilson Solar Observatory of the
Carnegie Institution of Washington

EDWIN B. ROBERTS
Yerkes Observatory of the
University of Chicago

HENRY C. GALE
Ryerson Physical Laboratory of the
University of Chicago

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EXHIBITED BY

EDWIN B. FROST

See Wm. B. PROBY,
Yerkes Observatory of the
University of Chicago.

WITH THE COLLABORATION OF

HUGH F. NEWALL, Cambridge University
ERNEST F. NICHOLS, Yale University
ALFRED PEROT, Paris
EDWARD C. PICKERING, Harvard College Observatory
ANNIBALE MODO, Osservatorio di Catania
CARL RUNGE, Universität Göttingen
ARTHUR SCHUSTER, The University, Manchester
FRANK SCHLESINGER, Allegheny Observatory

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BAND AND LINE SPECTRA OF IODINE

By R. W. WOOD AND M. KIMURA

Iodine vapor is of peculiar interest spectroscopically, in that it is one of the few substances which can be caused to emit line spectra of an almost infinite variety, of definite types, and very regular structure, by excitation with monochromatic light, as has been shown by one of us. These resonance spectra are very intimately associated with the complicated banded absorption and emission spectra, on which account it has seemed very desirable to make a comprehensive study of the spectra of this element excited by other means under the highest dispersion possible.

The present paper will deal chiefly with the electrical excitation of the vapor in vacuum tubes. In the course of the investigation we made the discovery that many of the lines of the line spectrum are complex under high dispersion, appearing as doublets, triplets, quadruplets, and quintuplets, the total width of the group in the case of the quintuplets being about 0.35 Å. These complex lines behave in a most remarkable manner in the magnetic field, and we made a very exhaustive study of the Zeeman effect which they exhibit. This subject will be taken up in a subsequent paper.

The different types of spectra emitted by iodine vapor under different conditions of excitation were studied by Konen¹ nearly

¹ *Annalen der Physik*, 65, 257, 1898.

twenty years ago. In vacuum tubes excited electrically he found a band spectrum and a line spectrum, the relative intensities of which depended upon the diameters of the tubes, current-densities, vapor-densities, and other circumstances. Konen gives the wave-lengths of about 350 lines in the range of spectrum from λ 3030 to λ 5787, but makes very little mention of the band spectrum, stating that it was so feeble that it could be photographed only with a direct-vision prism-spectrograph (exposure 8 to 9 hours) which gave a spectrum less than 3 cm in length for the range 5700-3000. We have, however, so improved the conditions of excitation that we have been able to photograph this band spectrum in the fifth-order spectrum of a large plane grating, with an objective of three meters focus—that is to say, with apparatus capable of completely resolving the absorption spectrum, which, as has been shown by one of us, contains in the neighborhood of 40,000 lines in the visible region. The spectrograms from which Konen's measurements of wave-lengths in the line spectrum were made were obtained with a small concave grating of one meter radius in the first-order spectrum, and he gives 0.04 Å as his mean error. We are, however, in agreement with Kayser, who considers the limit of accuracy to be more nearly 0.1 Å. Konen was unable to secure photographs in the second order on account of the faintness of the light. We have of course had no difficulty in photographing this spectrum in the fifth order, as the lines can be made very much brighter than the bands.

We found, in the early stages of the work that the insertion of a spark-gap or capacity in the circuit increased enormously the intensity of most of the lines and suppressed almost completely the band spectrum. There were, however, other lines which were reduced in intensity, and a few which showed little or no change. This circumstance has been mentioned briefly by Goldstein, and Stark has also alluded to it, classifying the lines which were increased in intensity as "spark lines," the others as "arc lines."

In the preliminary part of the work we had considerable difficulty in finding suitable electrodes. Platinum is very rapidly attacked by the ionized iodine vapor, and deposits in the form of a brownish coating of very low reflecting power, which is probably

a compound of the metal with iodine. We finally adopted tubes provided with external electrodes of tin foil. These tubes were of the form shown in Fig. 1. The bulbs were about 4 cm in diameter and 15 cm in length, joined by a capillary, which was blown out in the form of a thin bulb at *A*, for the emergence of the light. The process of exhaustion was as follows: A few flakes of iodine were introduced into the bulb through the tube *B*, which was then sealed. The flakes were then brought to the bottom of the tube *B*, and the tube *C* put in communication, through a U-tube immersed in liquid air, with a Gaede pump. If liquid air is not available, a tube filled with fragments of caustic potash should be introduced between the tube and the pump, to hold back the iodine vapor. During the process of exhaustion the bulbs must be strongly heated with a Bunsen flame. Before the tube is sealed off from the pump a small flame should be applied cautiously to the bottom of the tube *B*, until the iodine has entirely sublimed to the upper part of the tube. It is also a good plan to test the vacuum in the following way: Wrap the bulbs with tin-foil electrodes and start the discharge, using a coil capable of giving a six- or eight-inch spark; then touch the walls of the bulbs with cotton wet with liquid air. If the capillary is very fine, the vacuum in the bulb nearest the pump will usually be found to be much higher than in the second. At very low pressures the color of the discharge in iodine vapor is chamois-yellow, and the exhaustion should continue until this condition obtains in *both* bulbs, when they are cooled with liquid air or solid CO_2 . If neither of these substances is available, immerse the tube *B* in a mixture of ice and salt. A yellow discharge

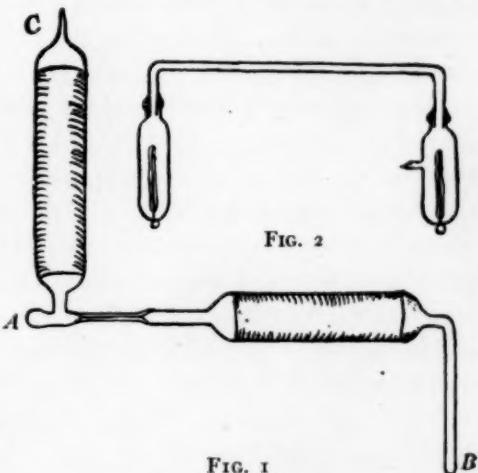


FIG. 1

FIG. 2

in one bulb and a pink discharge in the other indicate that nitrogen is still present in the bulb beyond the capillary.

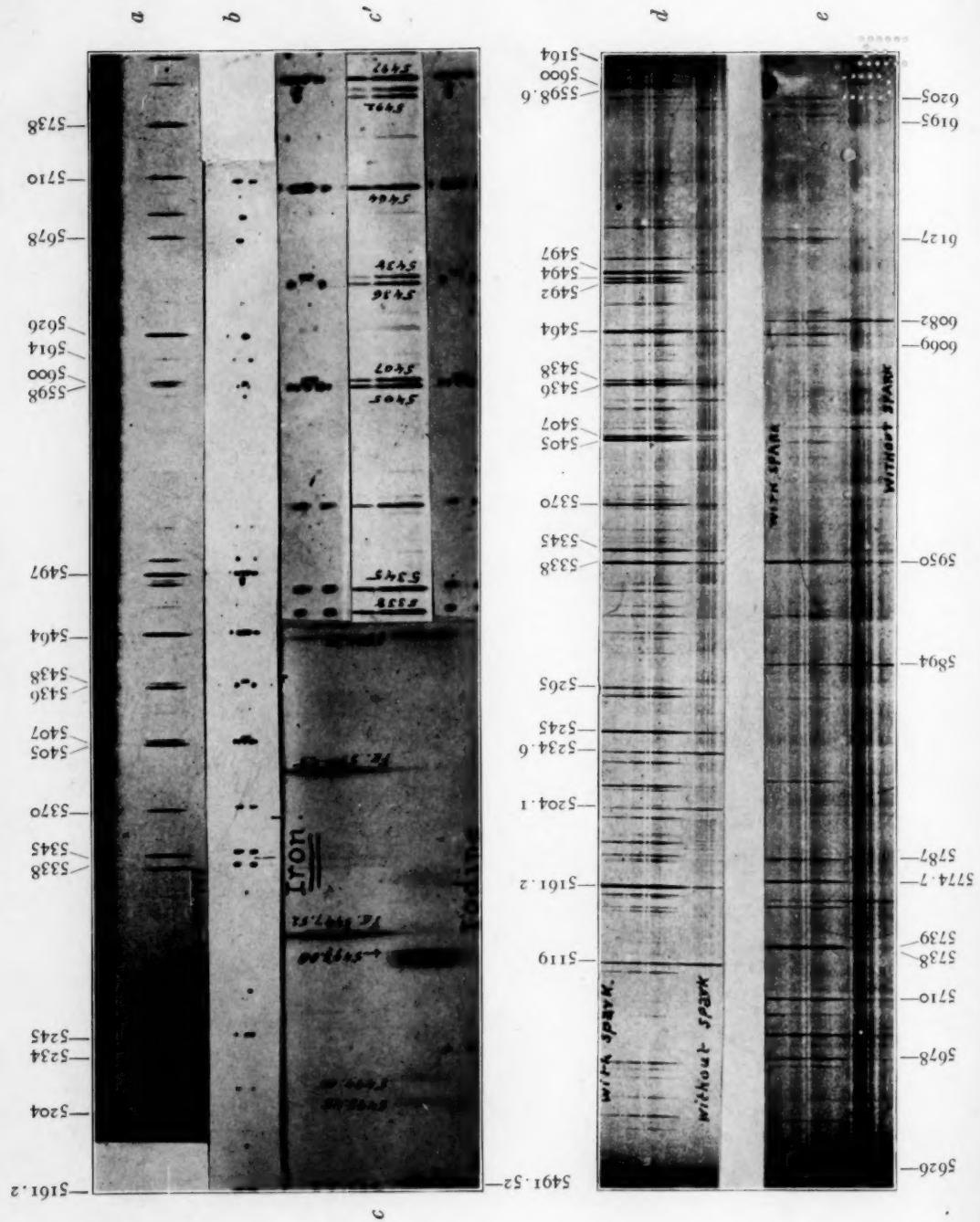
In our experiments we found that, to get the line spectrum at its brightest, the diameter of the capillary should be not over 0.15 mm, and considerable practice was required before suitable tubes could be produced. They were drawn down from 6 mm tubing, which was first heated until the walls nearly collapsed. In the latter part of the investigation we found that very satisfactory iodine tubes could be made by using electrodes of thin platinum foil enameled with a thin layer of soft glass, which was smeared on in the flame of a blast lamp. These electrodes last a long time, heavy currents can be used, and the capillary can be a millimeter or more in diameter.

The spectrum of the electrically excited iodine vapor is made up of a fluted band spectrum between wave-lengths 5200 and 7000, which in the fifth-order spectrum of the large plane grating shows a structure comparable to that of the absorption spectrum, and a continuous band between wave-lengths 4300 and 4800 Å. This latter band becomes relatively feeble if the iodine is at a low pressure, as when the lateral tube is placed in a refrigerating medium, and we have only the fluted band, the integrated color of which is the chamois-yellow referred to above. As the pressure increases, the color becomes white and finally violet-blue, owing to the development of the continuous band.

Superposed on the band spectrum we usually have the line spectrum also, though it is nearly absent in wide tubes with small current-densities. It may be developed by constricting the tube or by increasing the current-density, as by the introduction of a condenser in the circuit. With the tubes provided with external electrodes it can be brought out strongly by means of a spark-gap placed in parallel with the tube. It may also be brought out, as we found, by merely heating the discharge tube to a high temperature by means of a burner. This indicates that it probably results from the dissociation of the iodine molecule. As the line spectrum develops in intensity, the band spectra fade away and finally disappear. Even in the tubes provided with external electrodes we found that traces of CO appeared after prolonged use. A yel-

sec
sec
sec
sec
sec

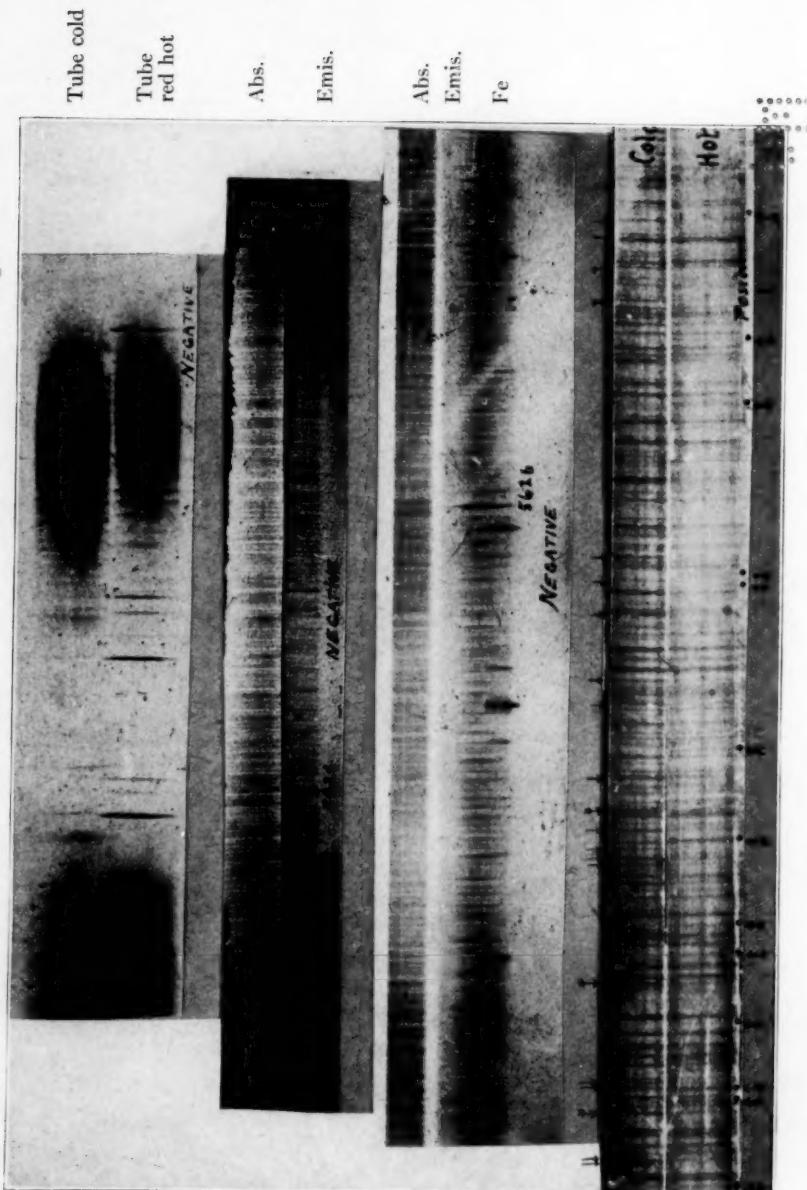
PLATE XIII



1900
1901
1902
1903
1904

PLATE XIV

Violet-blue Green Yellow Orange



low discoloration of the glass also developed, and it seems probable that this gas or CO_2 is liberated from the glass by the action of the ionized iodine.

A portion of the band spectrum with the lines superposed and the line spectrum alone are reproduced as negatives in Plate XIII, *a*. The latter was taken with a condenser in parallel (internal electrodes). The influence of the current-density is well shown by *d* and *e*, which reproduce the greater part of the visible spectrum. The lower portion of each was taken without spark, the upper with spark in parallel with the tube (external electrodes). For example, line 5234 is strong in the upper spectrum of *a* and the lower spectrum of *d*, while it has disappeared entirely in the lower spectrum of *a* and is relatively weak in the upper spectrum of *d*. Line 5245 behaves in exactly the reverse manner.

The disappearance of the band spectrum and the appearance of the lines can be brought about gradually by means of a variable capacity. We are of the opinion that it is the result of dissociation resulting from elevation of temperature, for we have succeeded in bringing about the same change by heating the narrow part of the tube with a Bunsen burner. The tube (Fig. 2) used in this experiment was provided with internal electrodes sealed into glass bulbs, which we joined by a quartz tube having a bore of about 3 mm, and cemented into the bulbs with sealing-wax. This tube, when excited by the coil, gave the band spectrum, with scarcely a trace of the lines (Plate XIV, *f* [upper spectrum]). The horizontal portion of the quartz tube was now strongly heated; the color of the discharge changed and the lower spectrum was obtained, with the band much weakened and the lines strongly developed.

The band spectrum has been photographed in the fifth-order spectrum of a seven-inch plane grating with a lens of three meters focus. A portion of the spectrum in the region of the 5626 line is reproduced on Plate XIV, *g*, in coincidence with the absorption spectrum. Since the photograph is reproduced as a negative, the absorption lines appear light instead of dark (upper spectrum). It is clear from the photograph that the spectra are not complementary, though every emission line of the band has an absorption line in coincidence with it. There are many absorption lines,

however, which are not represented in the emission spectrum. This very probably results from something in the nature of dissociation. We have not yet studied the possible changes in the fine structure of the emission band spectrum with varying current-density, but there are indications that such changes occur, for some of our plates show greater dissimilarity between emission and absorption than the one just mentioned— h for example.

The action of high temperature on the band absorption spectrum has been investigated, however, and changes have been noticed which throw some light on the matter.

EFFECTS OF HIGH TEMPERATURES ON THE ABSORPTION SPECTRUM

Evans has given, in the *Astrophysical Journal* (32, 1, 1910), an account of an investigation of the disappearance of the absorption spectrum of iodine at high temperatures. His investigations were made with a spectroscope of low dispersion, and only the gradual disappearance of the bands was recorded. His results would be perfectly explained on the supposition that the absorption spectrum results from diatomic molecules I_2 , which, at high temperatures, break down into monatomic molecules devoid of absorbing power. He found that the denser the vapor the higher the temperature necessary to cause the complete disappearance of the spectrum.

We have studied the phenomenon with a spectroscope of the Littrow type of six meters focus, using the fifth-order spectrum of the seven-inch grating. This grating, which is the best ruled by Anderson, gives very nearly its full theoretical resolving power (450,000). Photographs were made with dense iodine vapor in a quartz bulb (previously exhausted) heated by two blast lamps, and with the same bulb at room temperature, with much less dense vapor. We also made a large number of plates with a tube of pyrex glass heated in an electric oven. In every case we attempted to secure pairs of plates which showed the absorption spectrum at about the same degree of intensity, as this condition brought out the changes in the minute structure to better advantage. On the assumption that diatomic absorbing iodine breaks down into a colorless monatomic gas, we should expect the spectrum to fade away precisely as it does when the amount of vapor is decreased

by lowering the density. This is not the case, however, as will be seen by comparing the photographs (positives) reproduced on Plate XIV, *i*, the lower one taken with the quartz bulb at high temperature (perhaps 1000° C.), the upper with the bulb at a temperature of 35°. The stem of the bulb was immersed in boiling water in the first case; consequently the iodine was at a density corresponding to 100°. If we compare the two photographs, we notice that some lines are much stronger in the upper spectrum of the cold vapor than in the lower. Some of these lines have been indicated by arrows. Many lines have about the same intensity in both spectra. Others, however, are distinctly stronger in the spectrum of the hot vapor. These also are indicated by arrows and small dots.

It appears then that the lines are affected in different degrees by an elevation of temperature. Those indicated by the arrows above the upper spectrum are the most readily quenched, and those indicated by arrows below the lower spectrum are the ones most resistant to temperature. Clearly we are dealing with something more complicated than the dissociation of a diatomic molecule. Similar differences were found in the case of the spectra made with the tubes of pyrex glass at temperatures ranging from 350° to 500° C.

It seems quite possible that the band emission spectrum will be found to be much more nearly the exact complement of the absorption spectrum of the vapor at a high temperature than in the case shown in Plate XIV, *g* and *h*. This matter will form the subject of a future investigation.

THE LINE SPECTRUM

Though the wave-lengths which we have redetermined are probably not much more accurate than those given by Konen, it appears to be worth while to give them, as we have divided the lines into two groups, the arc and spark lines previously alluded to. Moreover, we have determined the wave-lengths of some 50 of the lines from plates made in the fourth-order spectrum of the 3-meter spectrograph, and these are correct to 0.01 Å. It is doubtful if the others can be relied on beyond 0.1 Å, and the same is true of Konen's values.

In Table I the "arc" lines, or the ones which show a *decrease* of intensity as a result of increasing the current-density by a condenser or parallel spark-gap, are indicated by an asterisk. It should be noticed, however, that this effect is of variable magnitude, some lines being greatly weakened, others less so; some lines show no change at all, and others (the spark lines) are enhanced in varying degrees. On this account it is difficult to make a very sharp classification. All wave-lengths are given on the international scale and the values in italic were determined from plates made in the fourth-order spectrum and are correct to within about 0.01 Å. The others are correct only to 0.1 Å.

STUDY OF THE COMPLEX LINES WITH THE ECHELON

Instruments and methods.—The echelon used in this work was a new one by Hilger, with twenty plates, 1 cm thick, in optical contact. It was used in conjunction with a collimator and telescope, each of 9 feet focus. It may be well to point out that this is about the right focal length to furnish the full resolving power recorded on a photographic plate. The telescopes of shorter focus usually employed, while excellent for visual observations, give poor results when used for photographic work. A wooden box surrounded the echelon and the objectives of the collimator and telescope, and the temperature within this inclosure was kept constant to within 0.1 C. by a toluole thermostat. The slit of the collimator was removed and its place taken by the second slit of a Hilger constant-deviation spectroscope, used as a monochromator. To make settings with this instrument we simply swung the 9-foot collimator a little to one side, and viewed the slit of the monochromator with a lens of high power, opening it wide for the purpose of identifying the line, and then gradually closing it while keeping the desired line always within the aperture. This method is far simpler and more satisfactory than attempting to form an image of one slit on another by means of a lens, and we were able to study separately lines the distance between which was only 7 angstrom units. Some of the lines showed such irregular structure with the echelon that we suspected the presence of neighboring lines that were not removed by the monochromator. This was found to be

TABLE I

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Without Spark	With Spark		Without Spark	With Spark
4632.4.....	4	10	4924.4.....	1	2
4634.8.....	1	8	4929.9.....	1	2
4640.7.....	2	10	4938.6.....	1	6
4657.4.....	1	6	4943.1.....	1	6
4663.8.....	1	6	4957.6.....	1	6
4666.5.....	4	12	4965.7.....	0	2
4675.5.....	6	10	4968.33.....	2	6
4676.5.....	1	8	4974.5.....	1	0
*4687.3.....	1	0	4984.4.....	1	2
*4691.1.....	1	0	4986.95.....	2	10
4700.8.....	0	0	*4991.9.....	1	0
4702.5.....	1	2	4992.2.....	1	2
4707.9.....	1	2	5008.4.....	0	4
4711.7.....	1	2	5028.8.....	1	2
*4722.1.....	1	0	*5032.3.....	1	0
*4726.3.....	1	0	5036.1.....	1	6
4730.5.....	1	8	5046.4.....	1	4
*4734.1.....	1	0	*5048.1.....	1	0
4737.1.....	1	2	5057.4.....	1	4
4742.9.....	1	2	5061.9.....	0	4
4752.7.....	1	2	5065.5.....	2	6
4763.4.....	10	10	*5068.2.....	1	0
4765.7.....	1	4	5090.7.....	1	4
4768.2.....	0	6	5098.8.....	1	2
*4773.1.....	1	0	5114.44.....	1	8
*4775.8.....	1	0	*5119.32.....	20	15
*4782.5.....	1	0	5124.6.....	1	2
4784.8.....	1	4	*5130.5.....	1	0
4787.2.....	1	2	5131.3.....	1	2
4788.2.....	1	2	*5133.2.....	1	0
4790.9.....	0	2	*5136.1.....	1	0
4799.8.....	0	4	*5138.5.....	1	0
4800.2.....	2	4	*5145.2.....	1	0
4806.4.....	2	6	5147.4.....	0	6
4808.0.....	0	2	5149.7.....	0	6
4828.3.....	2	6	5154.9.....	1	2
4835.1.....	2	6	5156.4.....	1	8
4850.4.....	2	10	5161.20.....	8	30
4853.1.....	1	2	5174.6.....	1	2
*4862.33.....	20	16	5175.1.....	1	2
4864.5.....	1	6	5176.3.....	1	2
4881.6.....	1	4	5178.1.....	1	8
4883.7.....	0	8	*5185.14.....	1	8
*4887.7.....	2	0	5186.3.....	1	0
4891.3.....	1	6	5189.4.....	1	2
4893.8.....	1	4	5198.9.....	1	8
*4896.72.....	12	8	*5204.08.....	10	4
*4902.2.....	4	0	5205.5.....	1	2
4908.5.....	1	2	5214.04.....	1	4
4910.3.....	1	2	5216.22.....	2	10
*4916.94.....	16	10	5228.93.....	0	8

TABLE I—Continued

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Without Spark	With Spark		Without Spark	With Spark
*5234.58	10	8	*5501.00	2	0
5245.65	4	15	5504.77	2	8
5265.150	2	10	5522.1	0	4
5265.266	2	10	5527.5	1	4
5266.8	2	2	5546.4	2	2
5269.36	2	10	5551.7	0	4
5288.7	0	4	5568.7	0	0
5296.7	1	2	5586.3	4	2
5299.68	0	6	5590.3	2	2
*5304.3	1	0	5593.09	0	4
5309.0	1	8	5598.55	2	6
5314.6	1	4	5598.68		
5322.71	0	6	5600.21	2	6
5326.4	1	4	*5601.8	2	1
5336.6	1	0	5603.2	2	4
5338.20	6	18	5612.82	2	6
*5341.8	1	0	5625.66	4	15
5345.17	6	18	5643.4	1	4
5349.7	1	2	5673.7	1	4
5351.9	1	2	*5678.06		
5356.0	1	4	5678.15	2	10
5367.5	2	4	5679.9	0	0
5369.75	4	12	5690.89	2	10
5372.5	1	4	*5690.96		
*5374.5	1	0	5702.07	0	2
5380.1	1	4	5710.43	2	10
5405.11			5723.5	0	0
5405.23	4	16	5725.0		
5405.38			5738.5	2	10
5405.59			5739.5	0	10
5407.35	2	12	5734.8	0	1
5411.7	1	4	5760.8	2	8
5415.0	0	4	*5764.3	6	4
5421.97	0	4	*5774.7	2	10
5422.71	0	4	*5780.4	2	1
*5427.4	6	4	*5787.1	1	6
5435.80	4	10	*5790.2	1	0
5437.97	2	8	*5793.0	1	0
5449.0	1	4	5819.6	1	2
5457.1	2	4	5830.0	1	6
5464.77	6	20	*5832.7	1	0
5468.1	1	2	5875.1	1	4
5475.1		0	*5893.8	8	6
5479.55	1	6	*5908.5	1	0
5491.52	1	8	5920.7	1	4
5493.45	0	8	*5928.6	1	0
5493.05			5950.1	4	10
5497.08			*5956.6	2	0
5496.96			*5960.0	2	1
5496.85	2	15	5962.8	0	1
5496.79			*5966.1	2	1
5496.73			*5967.7	2	1

TABLE I—Continued

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Without Spark	With Spark		Without Spark	With Spark
*5980.5.....	2	○	6257.4.....	1	4
*5984.2.....	2	○	6267.1.....	○	1
6007.6.....	1	2	6268.5.....	○	4
6015.8.....	1	4	*6276.8.....	1	○
*6023.9.....	6	2	*6280.3.....	1	○
*6036.5.....	1	○	6290.4.....	○	1
*6038.6.....	1	○	6291.3.....	1	2
*6041.4.....	1	○	*6293.9.....	6	2
6043.9.....	1	2	*6296.4.....	2	○
*6046.5.....	1	○	*6313.1.....	2	1
*6048.4.....	2	○	6320.9.....	1	4
*6053.0.....	2	○	6323.6.....	○	1
6068.8.....	1	4	*6330.2.....	2	○
6074.9.....	2	6	*6333.5.....	2	○
6078.2.....	1	2	*6337.9.....	4	2
*6082.3.....	10	6	*6339.5.....	6	2
6084.7.....	1	2	*6348.3.....	1	○
6086.8.....	1	2	*6350.9.....	1	○
6115.7.....	○	1	*6355.4.....	2	1
6125.4.....	1	2	*6359.1.....	4	2
6127.4.....	2	8	*6367.2.....	2	○
6132.9.....	1	2	*6371.6.....	2	○
6149.0.....	1	2	6375.8.....	○	1
6161.9.....	1	2	6378.2.....	○	1
*6187.0.....	1	○	*6411.1.....	2	1
*6191.6.....	4	2	*6415.2.....	2	1
6195.5.....	1	4	*6428.7.....	1	○
6200.4.....	1	4	6440.2.....	1	4
6204.7.....	○	6	6476.0.....	1	2
*6213.0.....	4	2	*6488.1.....	4	2
6229.2.....	○	2	6495.0.....	1	2
6232.9.....	1	2	6516.1.....	1	2
*6233.2.....	2	1	*6538.3.....	2	1
6236.3.....	1	4	*6560.3.....	4	2
*6240.2.....	2	○	6574.8.....	○	1
*6244.3.....	4	2	6578.0.....	○	4
6245.8.....	2	2	6579.8.....	○	1
6250.6.....	○	2	*6583.2.....	4	○
6255.5.....	1	2	6585.0.....	○	4

the case. In some cases, as we subsequently found, two complex lines were so close together that they were passed simultaneously through the slit of the monochromator. To overcome these difficulties we crossed the echelon with a plane grating of 15,000 lines to the inch, placing it with its glass plates horizontal, between the collimator and grating. The collimator lens was an ordinary telescope objective of 1 meter focus, and the spectrum was formed

by a Cooke photographic objective of four inches aperture and the same focal length as the collimator. The slit was reduced in length to about 0.1 mm by means of two strips of tin foil fastened on the inside with soft wax. The beveled edges were on the outside, which is the proper design for a slit, though many instrument-makers reverse matters and give us beveled edges on the inside, which sometimes causes spurious lines by reflection of oblique rays. If the slit of the spectroscope was opened wide, the echelon spectra of the complex lines could be seen in the broad images of the slit. The echelon was leveled and brought to the proper position by observing these spectra. The slit was then closed until it was reduced practically to a needle hole, and the echelon spectra contracted to vertical rows of minute dots or single dots, each row representing a complex line and each single dot a simple line. In this way it was possible to photograph with the echelon the entire iodine spectrum from violet to red on a single plate. We even succeeded in photographing the nitrogen band spectrum in this way. A photograph of a portion of the spectrum taken with the grating-echelon combination is shown in coincidence with *a*, the spectrum taken with the grating alone, on Plate XIII, *b*. A smaller portion of the spectrum more highly enlarged is shown by *c'*, the spectrum formed by the grating alone lying between the spectra formed by the echelon-grating combination. We shall take up now the structure of the various lines studied thus far, designating in each case whether the observations were made with the echelon alone or were from the plates made with the echelon crossed with the grating.

LINE STRUCTURE

In the case of many of the complex lines we made accurate determinations of the wave-lengths of the principal lines correct to 0.01 Å from photographs made in the fourth-order spectrum of the plane-grating spectrograph of 3 meters focus. These photographs also served as a check in interpreting the results obtained with the echelon. A portion of one of these is reproduced on Plate XIII, *c*, showing the complex line λ 5497. The constants of the echelon were as follows:

$$\mu_D = 1.57493, \quad C - D = 0.00410, \quad D - F = 0.00996, \quad F - G = 0.00837.$$

From these values we calculated the constants in the Hartmann formula,

$$\mu = \mu_0 + \frac{C}{(\lambda - \lambda_0)}$$

$$C = 141.09, \quad \lambda_0 = 1519, \quad \mu_0 = 1.54267.$$

The wave-length intervals corresponding to the distance of two successive orders were calculated from the formula

$$d\lambda_m = \lambda^2 \left\{ \frac{1}{1 \left[(\mu - 1) - \lambda \frac{d\mu}{d\lambda} \right]} \right\}$$

for various wave-lengths, and their values are given in Table II. A curve showing the relation between λ and $d\lambda_m$ was then drawn, from which the wave-length intervals between successive orders for any value of λ could be found.

TABLE II

λ	$d\lambda_m$
4632.4	0.3345
4666.0	0.3397
5016.2	0.4006
5162.0	0.4237
5345.0	0.4672
5464.6	0.4854
5625.0	0.5175
5691.0	0.5308
5875.0	0.5695

While some of the complex iodine lines showed an irregular structure, or appeared as close doublets, the majority exhibited a series of lines of four or five members decreasing in intensity and separation toward the region of short wave-lengths, thus ||||| . In the majority of cases the width of the group was less than the distance between the orders of spectra of the echelon. Obviously we cannot, on a single photograph, get a true record of the relative intensities of the lines making up the series, for, if we put the echelon in position of "single order" for the brightest line (first member of series), the last line will appear too faint in comparison, as it will be at or near the position of double order. We usually adjusted

the echelon so as to show the last or faintest line in "single order"; this made the first line relatively weak, but gave us a better record of the series for measurement. Two or three of the lines showed a series as wide as, or a little wider than, the distance between orders of echelon spectra. In this case the last member of the series falls upon or beyond the first member seen in the next order. In these cases, however, our photographs made with the grating in the fourth-order spectrum indicated the presence of the last member of the series, though it was not quite resolved, and by carefully comparing these photographs with those made with the echelon it was usually possible to determine the series. In the list which follows, the strongest line is designated by 0.000 and the distance of the other components from this zero position is indicated, the minus sign indicating of course the side of short wave-length.

Most of the lines in the violet prove to be single lines: the following showed structure:

$\lambda 4404$. Four lines nearly equidistant, 0.000, -0.057, -0.105, -0.167 from plates made by echelon crossed with grating.

$\lambda 4465$. Double lines; 0.000, -0.069.

$\lambda 4474$. Typical series of five lines of decreasing spacing and intensity. Strongest or main line 0.000, others at +0.078, +0.137, +0.190, and +0.232. This series appears to point toward longer wave-lengths. The other similar series point in the opposite direction. The reversal of this series was checked by a photograph made in the spectrum of the fifth order.

$\lambda 4632$. Structure similar to foregoing, but series turned the other way. Main line 0.000, others -0.085, -0.152, -0.196, -0.228. This line studied by the echelon alone.

$\lambda 5065$. Three components, +0.130, 0.000, -0.095 (echelon crossed with grating), middle component strong.

$\lambda 5161.20$. Series of five lines. Main line determined in fourth-order spectrum of grating. Components at -0.105, -0.186, -0.241, and -0.276 (by echelon alone).

$\lambda 5245.65$. Series of five lines. Main line determined by grating, which did not quite resolve the series. Echelon gave components at -0.053, -0.102, -0.146, and -0.192.

$\lambda 5265.150, 5265.266$. Double line by grating. Separation of components by echelon 0.119.

$\lambda 5338$. Close triplet by echelon alone. Main line strongest. Components at -0.041 and -0.083.

λ 5345. Components 1 and 2 faint, 4 and 5 fairly strong. Calling No. 3 the main line, we have for the structure (5 seems to be double) $+0.098$, $+0.029$, 0.000 , -0.051 , -0.10 , -0.116 .

λ 5356. Echelon crossed with grating shows five components spaced at nearly equal intervals, the width of the whole group being about 0.3 Å.

λ 5370. Series of five lines by echelon. Main line 5369.75 (by grating). Components of decreasing intensity at -0.054 , -0.099 , -0.146 , and -0.192 .

λ 5405.59. Main line and series of decreasing intensity. Four of the members of the series resolved by grating, namely, .59, .38, .23, .11. The series was a little wider than the distance between the orders of the echelon, the last member (the fifth) falling beyond the main line in the next order. The series would be shown to better advantage by echelon plates of 7 mm thickness. It could be studied only with the echelon crossed with the grating on account of the proximity of 5407 (a four-term series). It is represented thus: 0.00 , -0.21 , -0.36 , -0.48 , -0.55 . (The distance between echelon orders in this region is 0.473 .)

λ 5407. Echelon crossed with grating shows series of four lines of decreasing intensity, 0.000 , -0.062 , -0.115 , -0.160 .

λ 5436 is shown to be single, by echelon crossed with grating, and 5438 similar to the 5407 series but with closer spacing, 0.000 , -0.05 , -0.082 , -0.115 , and -0.161 .

λ 5464.77. Series of five components by echelon alone. Four shown with grating in fourth order. The first and strongest has wave-length given above, and the four others are of decreasing intensity and located at -0.106 , -0.190 , -0.255 , -0.275 .

λ 5491.50 is single; 5493.45 and 5494.05 (by grating) appear with echelon crossed with grating as a close doublet of about 0.13 separation—an example of a spurious result due to a confusing of orders.

λ 5497.08. Main line of five member series. Grating measurements gave others as 5496.96, .85, .79, and .73. On account of proximity of other lines, it could be further studied only with echelon crossed with grating, which gave 0.000 , -0.134 , -0.233 , -0.310 , and -0.343 .

λ 5598.6. A triplet, by echelon crossed with grating. Components 0.00 , -0.185 , and -0.310 (the latter faint).

λ 5600.2. Close doublet, separation of components about 0.05 Å.

λ 5603. Three components by echelon crossed with grating: 0.000 , -0.082 , and -0.159 .

λ 5612.8. A doublet with components 0.068 Å apart.

λ 5678. Doublet by echelon alone. Wave-lengths also determined by grating 5678.06 and 5678.15. Echelon gave 0.88 separation.

λ 5691. Echelon alone gave a bright line with fainter companion 0.078 Å toward red, and a very faint one at -0.10 toward violet. The grating alone gave 5690.89 and 5690.96.

$\lambda 5710$. A very complicated line. A strong triplet series with another strong line well separated from it on short wave-length side, and two or three fainter companions:

$$+0.066, \underline{0.00, -0.045, -0.073, -0.110, -0.179}$$

λ 5738.5. Single.

λ 5739.5. A triplet.

$\lambda 5774.7$. Five components by echelon crossed with grating. The arrangement of the dots suggests that we may have two superposed lines, as the dots are not quite in line.

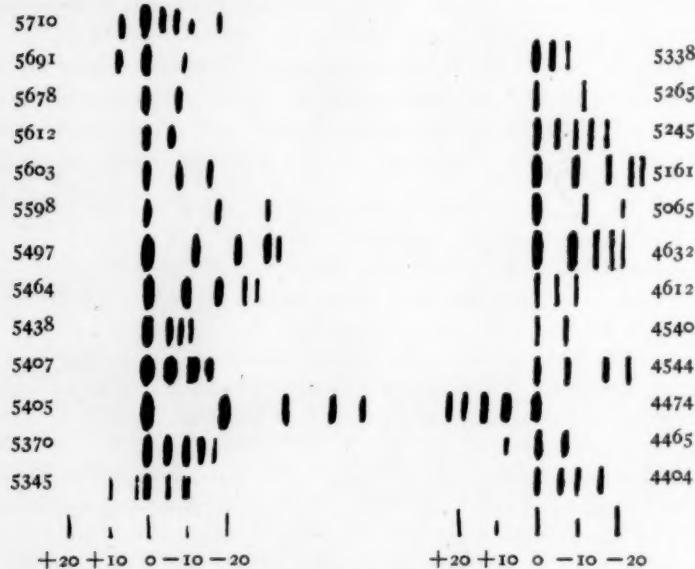


FIG. 3

The structures of these lines are shown by Fig. 3. The reversal of the series in the case of the line 4474 is of especial interest, as it was the only case found. It is also worthy of mention that all of the complex lines belong to the "spark" type. The width of the quadruplet series 5438 is only a little more than one-half of the distance between the first two members of the quintuplet series 5405, in which the separation of the members reaches its maximum value. In the following paper the behavior of these complex lines in a magnetic field will be discussed.

JOHNS HOPKINS UNIVERSITY
July 8, 1917

ZEEMAN-EFFECT FOR COMPLEX LINES OF IODINE

By R. W. WOOD AND M. KIMURA

In the previous paper we have given a description of the many complex lines which we have discovered in the spectrum of iodine electrically excited in vacuum tubes.

In the present communication we shall discuss the behavior of some of these lines in the magnetic field. A large number of the lines have a structure resembling that of a short series, thus, . We never observed a series of more than five members, and the width of the group varied from 0.16 to 0.50 Å. Paschen and Back¹ have shown that the close doublets of helium and the triplets of oxygen behave in a most interesting manner in the magnetic field, the oxygen triplet, for example, being transformed into a single line for the polarized component vibrating parallel to the field.

Our preliminary observations, which were made without polarizing apparatus, showed that the lines which had the structure figured above gave, in strong fields, a triplet of quite normal appearance. In weak fields the structure became too complicated to follow, and we immediately resorted to a polarizing apparatus by which the components vibrating parallel and perpendicular to the field could be studied separately. The tubes employed were of the same type as that described in the previous paper. The short capillary part of the vacuum tube was mounted between flat pole pieces, the field being essentially homogeneous in the region of the capillary. The tube was observed "end-on," i.e., in a direction perpendicular to the lines of force. A natural crystal of Iceland spar about 1.5 cm thick was used as a double-image polarizing prism. This was placed close to the capillary, and, when properly oriented, gave two polarized images very close together, the one immediately above the other. Real images of

¹ *Annalen der Physik*, 39, 897, 1912.

these were formed on the first slit of the Hilger constant-deviation spectroscope by means of a photographic objective of high quality. These images were about a millimeter in diameter, as we placed the lens much nearer the tube than the slit, and were separated by a distance of about 3 mm. Both polarized components could thus be photographed with the echelon simultaneously, and by raising the images about 1.5 mm on the slit we could obtain two more records showing the unmagnetized lines in coincidence with the magnetized ones. Various methods of bringing about this vertical shift were tried, but all were found unsatisfactory until the following simple expedient was adopted. A piece of plane-parallel glass (Michelson interferometer flat) was mounted a short distance from the slit of the Hilger spectroscope and arranged to rotate on a horizontal axis, by which it was possible to incline the plate from the vertical at the angle necessary to produce the requisite shift. A graduated paper scale and a light lever attached with sealing-wax, to give the desired rotation, completed the apparatus. The advantage of the plate is that it shifts the two converging beams *without changing their direction*. Acute prisms, and other devices which we tried, changed the direction of the beams, reducing or destroying entirely the illumination of the echelon. In taking our plates we recorded the current flowing in the magnet in each case, and subsequently determined our fields by comparing two deflections of a ballistic galvanometer, produced respectively by the quick removal of a small exploring coil from between the pole pieces and from the center of a standard solenoid giving a known field. This method could not be used for the stronger fields (above 1000 gauss), as the field in the coil was only 860 gauss with a current of 18 amperes. The stronger fields were measured by observing the Zeeman-effect on the green helium line 5016 (which is known to exhibit the normal effect) from the formula

$$H = \frac{\Delta\lambda}{0.94 \lambda^2} 10^4,$$

in which the wave-length is expressed in centimeters, and $\Delta\lambda$ is the separation of the outer components of the Zeeman triplet in a field of H gauss.

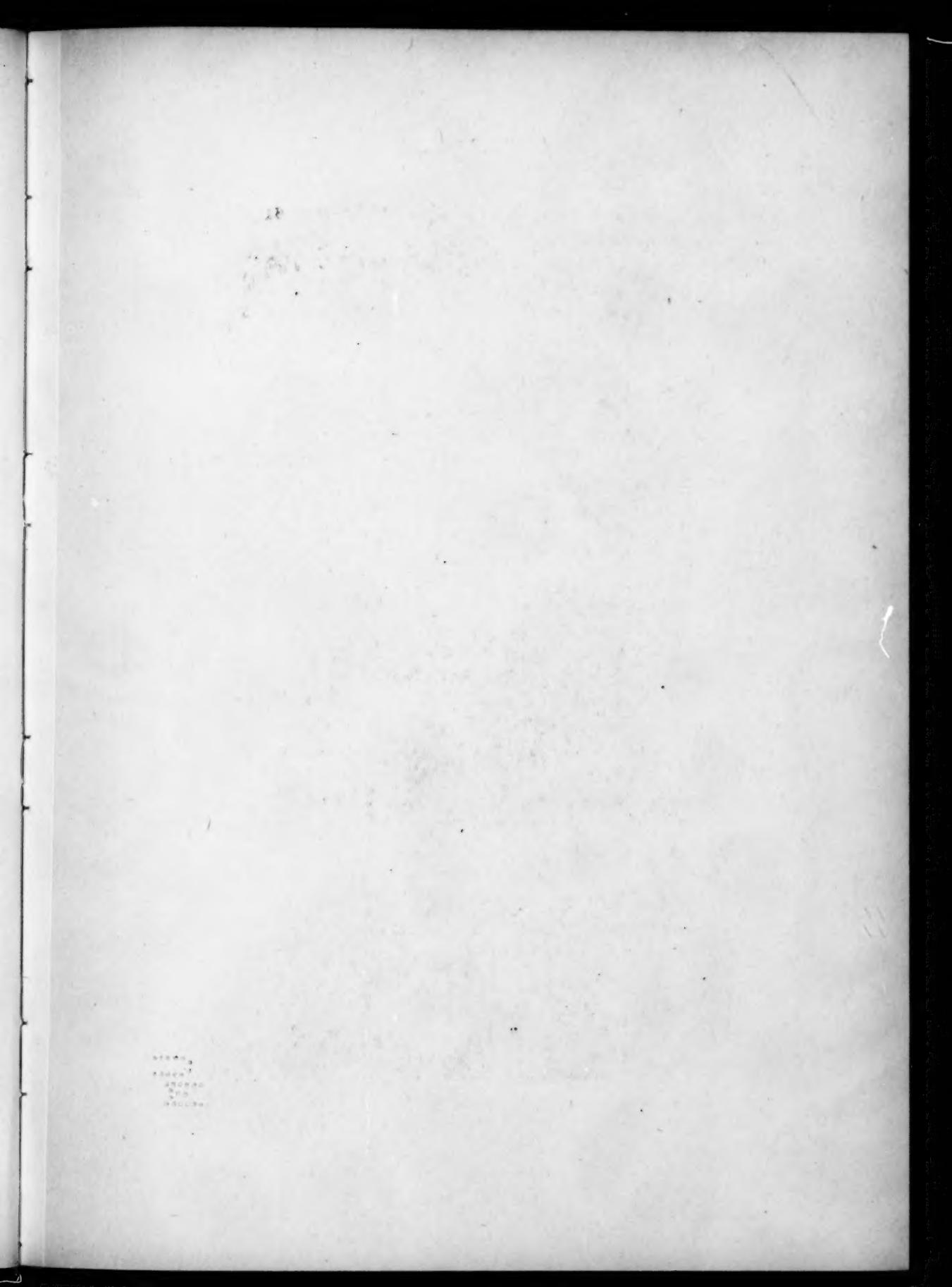
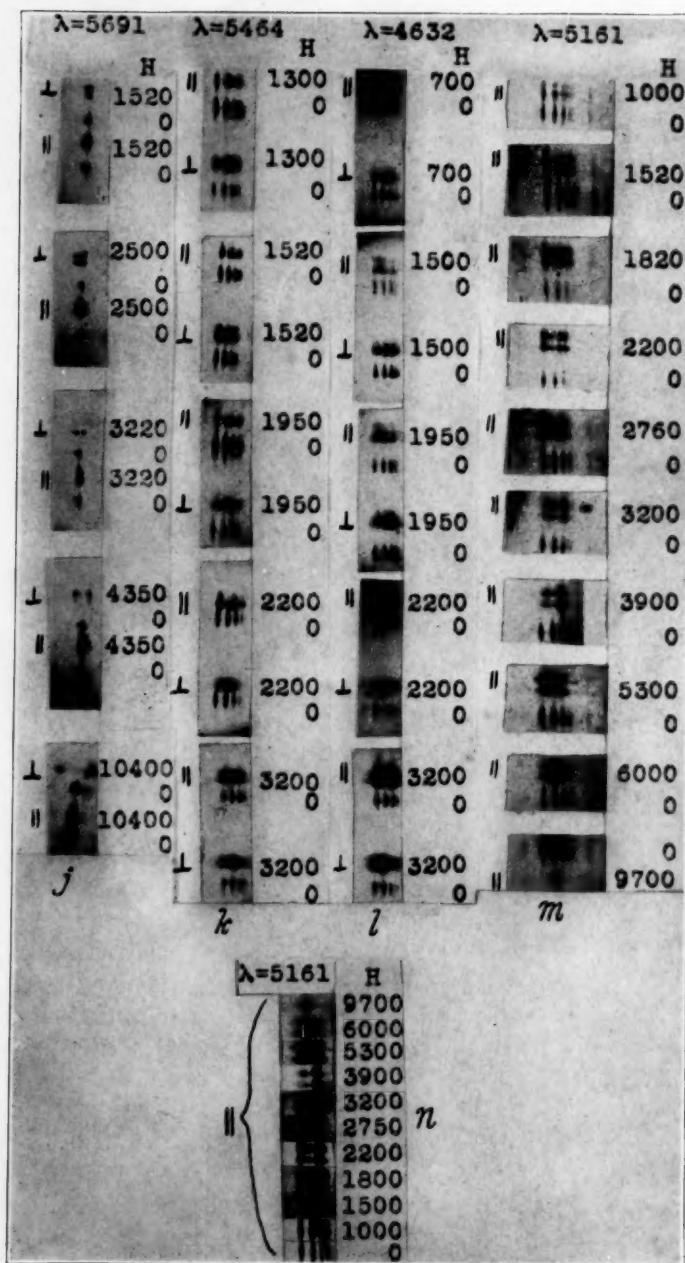


PLATE XV



The following lines were studied: $\lambda\lambda$ 5464, 5161, 4632, these having five components each, in the form of a series of decreasing intensity and spacing; $\lambda\lambda$ 5338 and 5345, each a close triplet; 5691, a doublet having one strong and one weak component; and 5624, a single line.

Photographs of many of the other lines were made, but only those mentioned above were measured. The resolving power of the echelon was not quite sufficient (20 plates of 10 mm each), and as a future investigation with a 40-plate echelon is contemplated by one of us, the results given in the present paper are to be regarded as preliminary in their nature.

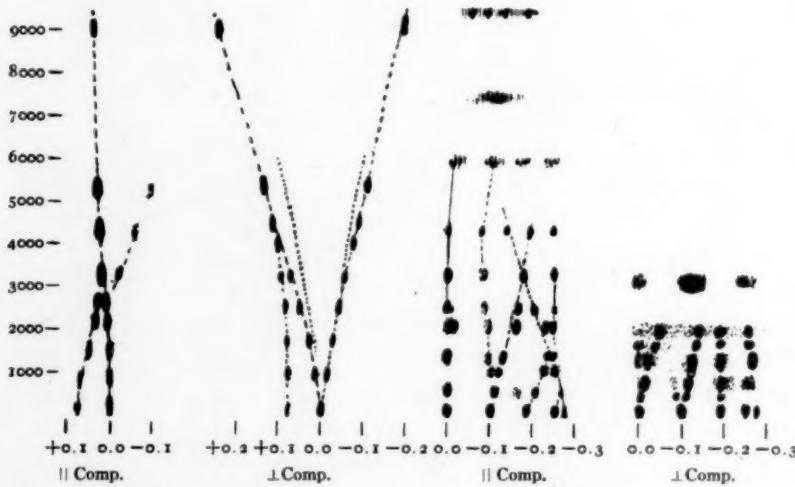
λ 5691

We shall begin with a discussion of the action of the magnetic field on this line, as its structure is very simple, a strong line with a fainter companion 0.078 Å on the side of longer wave-lengths. The behavior of the perpendicular and parallel components of polarization in fields of increasing strength is shown on Plate XV, *j*. Shorter wave-lengths are to the right in these figures.

In the case of the parallel component the main line remained undisplaced, as in the normal Zeeman-effect up to a field of about 2000 gauss, but its intensity increased and it showed a distinct broadening. The satellite, however, approached it and increased in intensity until, at about 2500 gauss, the intensities appeared about equal and the lines almost fused. At 3220 they had completely united into a single line with a wave-length intermediate between that of the main line and the satellite, with a faint companion on the side of short wave-lengths; with increasing field the bright line suffered a further displacement toward the red, the faint companion moving toward the violet and disappearing in fields above 5000. Over a dozen plates in all were made and measured, and the results are shown in the form of a graph in Fig. 1.

In the case of the perpendicular component, the main line was doubled, the separation being normal up to a field of about 2000 gauss, the satellite remaining unaffected. With an increase of field the satellite was deflected as if pushed along by the positive

branch of the doublet, the two finally fusing as shown in Fig. 1. As will be seen from the diagram, the resulting doublet continues to widen and at 9000 gauss is symmetrical with respect to a point midway between the main line and the satellite. This phenomenon of the fusing of the satellite with the main line in the case of the \parallel component, and with one of the branches of the doublet in the case of the \perp component, was observed also in the case of other iodine lines, and is in agreement with observations made by Nagaoka and Takamine on the lines of other elements. In strong

FIG. 1.— $\lambda 5691$ FIG. 2.— $\lambda 5464$

fields, and in the absence of the polarizing apparatus, we have a triplet, with its central component displaced (from the position originally occupied by the main line for zero field) toward the red. The dotted lines in Fig. 1 (\perp component) indicate the calculated separation for the normal Zeeman-effect.

$$\lambda 5464.77$$

This line consists of five components, decreasing in intensity and separation toward the side of short wave-length, suggesting a miniature Balmer series. The wave-length of the main line was

determined by the grating, and the components are located at -0.106 , -0.190 , -0.255 , and -0.275 , the latter being very faint and not appearing resolved in the reproduction. The appearance of the composite line is shown on Plate XV, *k*. For each field-strength the parallel and perpendicular components of polarization are shown in coincidence with the line in zero field.

We will consider first the behavior of the components of vibration parallel to the field. Notwithstanding the fact that the parallel component is unaffected by the field in the normal Zeeman-effect, in the case of this complex line, the three members of shorter wave-length are so sensitive that even the residual magnetism of the electromagnet, after the current was shut off, was sufficient to alter the appearance of the series in a very marked manner, and this for the *parallel* component, ordinarily uninfluenced. On this account it was necessary to demagnetize the magnet very carefully, by repeatedly reversing and diminishing the current, until no appreciable attractive force was exerted by the poles for a piece of soft iron. It was also important not to pass from a strong to a weak field without demagnetization.

The behavior of the lines, when only the parallel components of vibration are recorded, is shown by Fig. 2. In a field of only 150 gauss a very distinct effect was observed on the two lines of shortest wave-length (-0.255 and -0.275), and at 500 gauss they fused into a single line. The line at -0.190 first widens, and at 600 gauss becomes double. We now have five lines, as in the beginning, though with a different spacing and distribution of intensity. If this were an isolated observation, one might erroneously conclude that the magnetic field had merely pushed the lines closer together. As the field increased in strength the negative branch approached, and finally fused with, the line formed by the fusion of the two referred to above, which appears to move slightly in the positive direction to meet the other line. The other branch (positive) formed by the division of -0.190 could not be followed beyond 600 gauss. The further behavior of these lines with increasing field is well indicated by the figure. The line formed by the fusion of the three lines just referred to divides again, one member increasing its wave-length, the other remaining fixed. The component

at -0.106 divides as indicated, the negative branch, which is strongly displaced, fusing with the positive branch mentioned above. The positive branch, which is much fainter, remains almost in coincidence with the original line. These changes can be followed on Plate XV, *k* (upper figures marked ||). Above 3000 gauss it is difficult to interpret the plates, as the components become hazy. At 3400 gauss we have four lines, and at 4400 gauss five lines again, the probable manner of transition being indicated in Fig. 2. At 6000 gauss we again have but four lines (hazy). At 7500 we found a continuous background, with a hazy line in the center, but we were unable to trace out the transition.

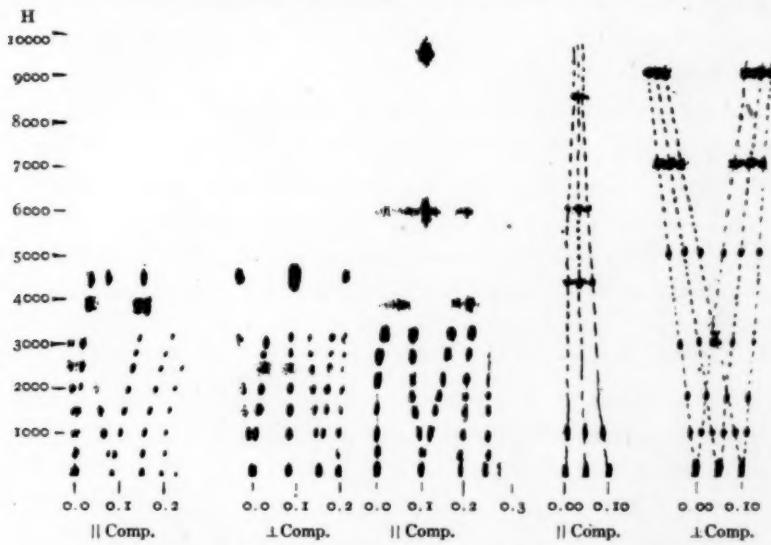
The perpendicular component of polarization is affected in a very different manner. The third line of the series remains undisplaced in fields below 2000 gauss, the first and second lines giving strongly displaced negative branches and very faint positive branches, which show little displacement and are difficult to follow. At 3200 there is a strong central component and two lateral fainter components, but we have not been able to determine from the plates just how the transition takes place, nor have we followed the development of the hazy doublet which appears in very strong fields.

$\lambda 4632$

The behavior of this line was studied in fields up to 4000 gauss and is shown graphically in Fig. 3. Normally it is a five-line series similar to $\lambda 5464$, but it is affected in a different manner. For the parallel component line No. 1 broadens and shows a suggestion of doubling. No. 2 doubles, the positive branch disappearing in fields above 2000, the negative remaining up to over 3000. No. 3 is unaffected up to 1000 gauss, then deviates rapidly in a negative direction. No. 4 is also displaced in the same direction. At 3900 gauss we have a doublet. For the perpendicular component of polarization, lines Nos. 1 and 3 double and 2 and 4 remain unaffected. The resolving power of the echelon was insufficient to accomplish more than a suggestion of this doubling, however, in the widened lines. At 4900 we have a triplet with a strong middle component. The behavior of the line is shown on Plate XV, *l*.

$\lambda 5161$

The parallel component only was studied in the case of this line, which is a five-line series similar to $\lambda 4632$ and $\lambda 5464$. Its behavior is shown by Fig. 4. The first line of the series exhibited only a slight widening and slight displacement toward the violet as the field-strength increased. The second line behaved in a remarkable manner. It became distinctly double in a field of 1000 gauss, and at 1820 the two components were widely separated. The doubling was not symmetrical, however, for the positive branch attained its maximum displacement at 1820, while the negative

FIG. 3.— $\lambda 4632$ FIG. 4.— $\lambda 5161$ FIG. 5.— $\lambda 5345$

branch continued to move toward the violet with increasing field. The positive branch eventually fuses with line No. 1, which moves over to meet it (4000 gauss). The displacement of the negative branch was proportional to the field-strength up to 3500 gauss. Line No. 3 was very slightly displaced toward the violet with increasing field and fused with the negative branch of No. 2 at 5000 gauss. Lines Nos. 4 and 5 fused at 500 gauss and faded away above 3000 gauss. At 6000 gauss we have a broad hazy line in the position of line No. 2, and at 9700 gauss it is found slightly

at -0.106 divides as indicated, the negative branch, which is strongly displaced, fusing with the positive branch mentioned above. The positive branch, which is much fainter, remains almost in coincidence with the original line. These changes can be followed on Plate XV, *k* (upper figures marked $||$). Above 3000 gauss it is difficult to interpret the plates, as the components become hazy. At 3400 gauss we have four lines, and at 4400 gauss five lines again, the probable manner of transition being indicated in Fig. 2. At 6000 gauss we again have but four lines (hazy). At 7500 we found a continuous background, with a hazy line in the center, but we were unable to trace out the transition.

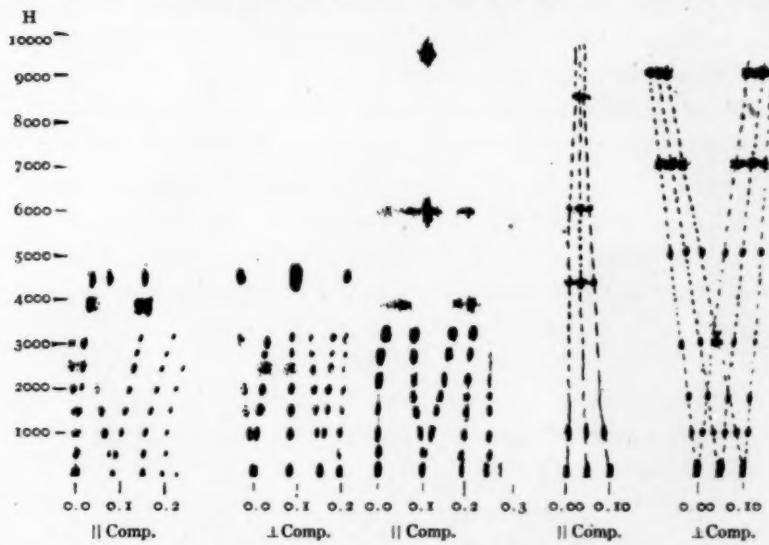
The perpendicular component of polarization is affected in a very different manner. The third line of the series remains undisplaced in fields below 2000 gauss, the first and second lines giving strongly displaced negative branches and very faint positive branches, which show little displacement and are difficult to follow. At 3200 there is a strong central component and two lateral fainter components, but we have not been able to determine from the plates just how the transition takes place, nor have we followed the development of the hazy doublet which appears in very strong fields.

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The behavior of this line was studied in fields up to 4000 gauss and is shown graphically in Fig. 3. Normally it is a five-line series similar to $\lambda 5464$, but it is affected in a different manner. For the parallel component line No. 1 broadens and shows a suggestion of doubling. No. 2 doubles, the positive branch disappearing in fields above 2000, the negative remaining up to over 3000. No. 3 is unaffected up to 1000 gauss, then deviates rapidly in a negative direction. No. 4 is also displaced in the same direction. At 3900 gauss we have a doublet. For the perpendicular component of polarization, lines Nos. 1 and 3 double and 2 and 4 remain unaffected. The resolving power of the echelon was insufficient to accomplish more than a suggestion of this doubling, however, in the widened lines. At 4900 we have a triplet with a strong middle component. The behavior of the line is shown on Plate XV, *l*.

$\lambda 5161$

The parallel component only was studied in the case of this line, which is a five-line series similar to $\lambda 4632$ and $\lambda 5464$. Its behavior is shown by Fig. 4. The first line of the series exhibited only a slight widening and slight displacement toward the violet as the field-strength increased. The second line behaved in a remarkable manner. It became distinctly double in a field of 1000 gauss, and at 1820 the two components were widely separated. The doubling was not symmetrical, however, for the positive branch attained its maximum displacement at 1820, while the negative

FIG. 3.— $\lambda 4632$ FIG. 4.— $\lambda 5161$ FIG. 5.— $\lambda 5345$

branch continued to move toward the violet with increasing field. The positive branch eventually fuses with line No. 1, which moves over to meet it (4000 gauss). The displacement of the negative branch was proportional to the field-strength up to 3500 gauss. Line No. 3 was very slightly displaced toward the violet with increasing field and fused with the negative branch of No. 2 at 5000 gauss. Lines Nos. 4 and 5 fused at 500 gauss and faded away above 3000 gauss. At 6000 gauss we have a broad hazy line in the position of line No. 2, and at 9700 gauss it is found slightly

displaced from this position toward the violet. These changes are shown on Plate XV, *m* and *n*, the latter figure showing the group in ten different stages, from zero field up to 9700 gauss, with the photographs mounted in coincidence.

λ 5338

In a weak field the main line of this triplet was decomposed into a triplet with normal separation and polarization. The satellite at -0.041 was also decomposed into a triplet, but the component lying on the side toward the main line suffered a greater displacement than the one lying on the other side of the central component. The same was true of the satellite at -0.083 except that the dis-symmetry was even greater.

In strong fields we have a diffuse triplet which forms in the manner indicated by Fig. 5, which is, however, the graph for the similar line λ 5345.

λ 5345

The behavior of this line is similar to that of λ 5338, and the measurements made from the plates are recorded in Fig. 5.

λ 5625

This is a single line and gave a symmetrical triplet, with a separation somewhat greater than that of a normal triplet.

$$\text{For normal triplet } \frac{\Delta\lambda}{\lambda^2 H} = 0.94 \times 10^{-4}.$$

$$\text{For } \lambda 5625, \quad = 1.26 \times 10^{-4},$$

that is, in the ratio 3:4.

The chief points of interest which have been brought out in this investigation may be summed up as follows:

The complex lines having the form of a series with decreasing intensity and separation are not all affected in a similar manner by the magnetic field.

In the case of any given complex line the components are affected to very different degrees. Certain components may not be affected at all, while others break up into doublets, the components of which

sometimes fuse with neighboring components and sometimes fade gradually away as the field-strength increases.

In the case of the perpendicular components of polarization we have not traced the development of the widely separated hazy doublet which appears with strong fields from the complex which develops in weak fields. This will require a somewhat higher resolving power than that available in the present work. Obviously the method of the non-homogeneous field would be especially adapted to the study of these complex lines, as the transition could then be traced by very gradual steps. We made some experiments along these lines, with flattened capillary tubes and pointed poles, but the results were not very satisfactory. With the tubes used in the latter part of the work, with internal electrodes, described in the previous paper, it seems probable that excellent results can be obtained in this way.

JOHNS HOPKINS UNIVERSITY
July 8, 1917

PHOTOGRAPHIC EFFECTIVE WAVE-LENGTHS OF SOME SPIRAL NEBULAE AND GLOBULAR CLUSTERS

By KNUT LUNDMARK AND BERTIL LINDBLAD

The method of determining color or spectral type based on the measurement of the photographic effective wave-length in grating spectra, especially developed by E. Hertzsprung¹ and by A. Bergstrand,² has, as far as we know, until now been applied only to point-shaped objects, fixed stars, and planetary satellites. There is, however, nothing to prevent the use of this method for celestial objects showing a clear surface, provided it is small enough, so that the spectra of the first order and the central image do not begin to overlap. If the time of exposure is sufficiently short, spectra of the first order become almost congruent with the central image, while they elongate when the intensity of image increases. The effective wave-length is calculated by measuring the distance between the two spectra, in doing which we follow the practice of bisecting the blackened surface.

In this investigation we have turned our principal attention to the spiral nebula. As the derivation in the usual way of the color-index of these objects might be beset with considerable difficulties, it seems as if the method of effective wave-length could in this case be of comparatively great importance. As a matter of course, different objects require different instruments. The images should not be very large and diffuse; in this investigation they do not, in some cases, differ very much from images of fixed stars, while some show a considerable surface, as, for instance, M 5 and M 82.

¹ "Sur la dispersion atmosphérique," *Bulletin astronomique*, 25, 5, 1908; "Über die Verwendung photographischer effectiver Wellenlängen zur Bestimmung von Farbenäquivalenten," *Potsdam Publications*, 22, No. 1, 1911; further, several articles in the *Astrophysical Journal*.

² "Über die Abhängigkeit der atmosphärischen Dispersionswirkungen von den Sterngrößen," *Astronomische Nachrichten*, 177, 241, 1908; "Recherches sur les couleurs des étoiles fixes," *Nova Acta R. Soc. Scient. Upsala* (IV), 2, No. 4, 1909; also in *Comptes rendus*, 148, 1079, 1909.

The instrument employed was a twin 6-inch astrographic telescope at the Upsala Observatory with Zeiss triplet lenses (aperture 15 cm, focal length 150 cm). A wire grating (the grating constant $c = 1.3422$ mm) was placed, with the wires in the direction of right ascension, in front of one objective (No. I); with the other objective a plate was taken without grating. The plates used were Imperial S. S. Emulsion 9220 A, Speed No. (H.O.D.) 275. The measurements were made by both of us with the Repsold measuring machine.¹

The applicability of this telescope for the determination of effective wave-lengths has been examined by Bergstrand and Lindblad,² and the result of the trial was upon the whole encouraging. Some doubt remained as to the fitness of the instrument for very faint images. Since then the objectives have been altered a little, through corrections of the position of their middle lenses, in order to produce the best possible images over as large a part of the fields as possible. It appears that this change has been of advantage also in the applicability of the instrument to the determination of effective wave-lengths. As the matter in question here is very faint images, the so-called photographic *Purkinje-effect*, i.e., the dependence of the effective wave-length on the intensity of image, will be of great importance. For the refractors, the achromatization here plays a large part. By the focusing here employed the wave-lengths are united at $400 \mu\mu$ and $443 \mu\mu$, while the mean effective wave-length is at about $424 \mu\mu$, thus fairly central. The spectrum obtained from a star with short exposure is at first almost rectangular, but with longer exposure it gets more and more elliptical, sometimes more irregularly oval in shape. The effect in question shows itself as a general tendency to an increase of the effective wave-length, with the intensity of image somewhat stronger for yellow stars than for white ones. In order to control the effect for a celestial object with a clear surface, we

¹ Bergstrand, "Recherches sur les couleurs des étoiles fixes," *Nova Acta R. Soc. Scient. Upsala* (IV), 2, 10, 1909.

² "Om bestämmningen af de fotografiskt effektiva våglängderna i fixstjärnspectra," *Arkiv för Matematik, Astronomi och Fysik* utgivet af K. Svenska Vetenskapsakademien, 11, No. 17, 1916.

have photographed Saturn with different exposures and have measured the effective wave-lengths. As appears from Table I, the rate in the λ values is at first quite imperceptible; but at the exposure time of 32^s a tolerably strong increase sets in. The

TABLE I

SATURN: PLATE TAKEN APRIL 25, 1917
SIDEREAL TIME 12^h14^m–12^h24^m

EXPOSURE TIME	OBSERVER		DIFFERENCE LK. – LD.
	Lundmark	Lindblad	
4 ^s	μμ	μμ	μμ
1	432.5	432.2	+0.3
1	32.7	28.5	+4.2
1	33.0	33.7	-0.7
1	33.0	34.7	-1.7
3	32.7	31.9	+0.8
3	34.3	34.7	-0.4
10	32.5	31.2	+1.3
10	32.3	32.8	-0.5
32	39.6	39.0	+0.6
32	38.5	39.9	-1.4
100	43.8	43.8	0.0
100	443.3	443.8	-0.5

MEANS

Exposure time	λ_{eff}
4 ^s	432.3
1	32.6
3	33.4
10	32.2
32	39.2
100	443.7

intensities of images which occur in connection with other objects included in this investigation are all considerably weaker than this critical intensity of image. Otherwise the two series of measurements show no perceptible personal equation for the two observers.

$\frac{\Delta\lambda_{\text{eff}}}{\Delta_{\text{atm}}}$ has been assumed to be 2 $\mu\mu$, in accordance with a determination made by Lindblad, using stars of different types of spectrum.

In his work already referred to, Hertzsprung¹ has assumed $\frac{\Delta\lambda_{\text{eff}}}{\Delta_{\text{atm}}}$ to be $3.5 \mu\mu$, valid for white stars (the Pleiades). In a footnote he remarks that this correction seems to be smaller for yellow stars than for white ones.

The grating-constant was determined from micrometric measurements as $c = 1.3422$ mm, and from the measured distance of η and b of the Pleiades was obtained with the use of W. Elkin's² measurements $f = 1485.5$ mm.

TABLE II

Date	Sidereal time	Exposure	Object	Observers	Remarks
1917 Feb. 16..	7h53m3—10h25m7	2h 9m	M 81, M 82, N.G.C. 3077	*Lk., Ld.	Cloudy
22..	6 18.8—10 54.8	4 34	Same object	Lk.	Clouds at the end of exposure
Mar. 15..	11 56.9—13 41.9	1 45	M 94	Lk.	From the beginning of the exposure very fine sky; clouds at the end
22..	10 39.7—12 9.7	1 30	M 3	Lk., Ld.	
27..	11 15.6—14 15.6	3 0	M 51, W.H.I. 186	Lk., Ld.	Sky very good
April 19..	12 16.8—16 31.0	(1 40)	M 64, W.H.I. 84	Lk., Ld.	
25..	13 22.6—15 0.6	1 30	M 57	Ld.	
May 10..	14 10.5—16 32.0	2 21	M 53	Lk., Ld.	
11..	14 36.5—16 36.5	2 0	M 5	Lk.	
17..	14 55.0—16 55.0	2 0	M 94	Lk., Ld.	Some haze

*Lk. = Lundmark; Ld. = Lindblad.

If s is the distance in mm between two spectra of the first order, we can put in this case with sufficient accuracy:³

$$\lambda_{\text{eff}} = \frac{c}{2} \cdot \frac{s}{f}$$

or

$$\lambda_{\text{eff}} = 451.74 \mu\mu \cdot s$$

Before proceeding to a statement of the measurements and their results, we give (in Table II) a summary of the plates we have had at our disposal for this investigation.

¹ "Über die Verwendung photographischer eff. Wellenlängen, etc.," *Astronomische Nachrichten*, 177, pp. 24–25, 1908.

not here

² "Revision of the First Yale Triangulation of the Principal Stars in the Group of the Pleiades," *Trans. of the Obs. of Yale University*, 1, 1887–1904.

³ Bergstrand, "Recherches," etc., *Nova Acta R. Soc. Scient. Upsala* (IV), 2, 17–18, 1909.

As the aim of the present investigation is in the first place to find out whether the connection between the effective wave-lengths and the spectral type of the stars found by Bergstrand¹ and by Hertzsprung² also exists between the corresponding elements for spiral nebulae and globular clusters, the objects examined have with preference been chosen among those whose type of spectrum is known.

From plates taken for a more extensive work, for which he has made preparations and on which he is engaged, Lindblad has found, when only the faintest measurable images are taken into consideration, that the following relation between the effective wave-lengths and the type of spectrum of the stars is obtained for the instrument employed by us:

A.....	415 $\mu\mu$
F.....	420 $\mu\mu$
G.....	427 $\mu\mu$
K.....	433 $\mu\mu$

These measurements show that for the Upsala 6-inch astrophotographic the spectral interval A to K (about 1^{mo} in color-index) corresponds to 18 $\mu\mu$ in effective wave-length. It is evident that the instrument is especially appropriate for the determination of effective wave-lengths from the fact that, for the great Meudon reflector³ and the 60-inch reflector⁴ of Mount Wilson Solar Observatory, both of which instruments are especially adapted for the determinations in question, the corresponding interval is, respectively, 21 $\mu\mu$ and 24 $\mu\mu$.

The measurements have been corrected for the effect of the selective extinction in our atmosphere, whereby, owing to the different qualities of the material, we shall here treat separately the objects investigated.

¹ "Recherches sur les couleurs des étoiles fixes," *Nova Acta R. Soc. Scient. Upsala* (IV), 2, 4, 36, 1909.

² "Effective Wave-Lengths of 184 Stars in the Cluster N.G.C. 1647," *Mt. Wilson Contr.*, No. 100, 1915; *Astrophysical Journal*, 42, 92, 1915.

³ Bergstrand, "Recherches," *Nova Acta R. Soc. Scient. Upsala* (IV), 2, 36, 1909.

⁴ Hertzsprung, "Effective Wave-Lengths of 184 Stars," etc., *Mt. Wilson Contr.*, No. 100, pp. 3, 19.

M81=N.G.C. 3031

By accident the images had been doubled on the longer-exposed of the two plates, containing this and the two following nebulae. Thanks to the circumstance that the displacement had taken place nearly at right angles to the direction of the length of grating spectra, the two images, owing to their closeness to each other, could be measured as a whole. With the aid of the pairs of horizontal wires in the measuring microscope it was possible to measure only the stronger of the two images. The measurements, which in the two cases agreed well, gave $\lambda_{\text{eff}} = 435.7 \mu\mu$. The plate of February 16 showed fairly faint images, which, however, could without any difficulty be measured, and from which was obtained $\lambda_{\text{eff}} = 435.8 \mu\mu$. E. A. Fath¹ has found that the total spectrum of this nebula exactly resembles the spectrum of a K-type star. *When we assume that the relation between the λ_{eff} and the spectral class of the stars, derived by Lindblad, also can be employed for the objects included in this investigation*, we find that the λ_{eff} for M81 determined by us also corresponds to the spectral class K.

M82=N.G.C. 3034

This was measurable only on the plate having the longest exposure. In this case the two images could not be distinguished, owing to the extension of the object. It was possible to measure only a bright nucleus close to the center. This nucleus occurs to the right of the center of the nebula on Isaac Roberts' photograph.²

Our measurements, which nevertheless were rather uncertain, gave $\lambda_{\text{eff}} = 415 \mu\mu$, which wave-length should correspond to the spectral type A. It is to be hoped that a long exposure will show whether any difference in effective wave-length or spectral type, respectively, exists between the central and the exterior parts of the nebulae. As far as we know, no determinations of the spectral class of this nebula exist.

¹ First Paper: "The Spectra of Some Spiral Nebulae and Globular Star Clusters," *Lick Observatory Bulletin*, No. 149, 1909; Second Paper: "The Spectra of Spiral Nebulae and Globular Star Clusters," *Mt. Wilson Contr.*, No. 49, 1911; *Astrophysical Journal* 33, 58, 1911; Third-Paper: *Mt. Wilson Contr.*, No. 67, 1913; *Astrophysical Journal* 37, 198, 1913.

² *Celestial Photographs*, 1, 1893, Plate 25.

W.H. I.286=N.G.C. 3077

The λ_{eff} was determined from the plate that was taken on February 22 and is probably very well established, although the images of the grating-spectra were rather faint. A mean value of $\lambda_{\text{eff}} = 428.6 \mu\mu$ was obtained. The spectrum of this nebula is unknown. The effective wave-length obtained corresponds to the spectral class G.

M 94=N.G.C. 4736

As this nebula has small extent on our plates (1 mm corresponds to $2'.28$), and as its light is strongly concentrated in the more central parts,¹ the effective wave-length could be measured with very great accuracy. If in the measurements only the starlike nucleus (the central condensation) was taken into consideration, a considerably greater value for the effective wave-length was obtained than if regard was paid to the image of the whole nebula, which on the grating-plate measured in diameter about $30''$ and consequently contained at least a part of the spiral branches lying very close to the central nucleus. From several sets of measurements, showing a good mutual agreement, there was obtained for the nebula in its entirety $\lambda_{\text{eff}} = 426.7 \mu\mu$ and for the nucleus $\lambda_{\text{eff}} = 432.9 \mu\mu$. Fath's² three spectrograms do not agree with one another, yet it may be gathered from his later investigations (Mount Wilson plates) that the spectrum of the nebula must belong to the G-type. The effective wave-length for the nebula in its entirety obtained by us corresponds exactly to the same spectral type. F. H. Seares³ has recently shown that the central nucleus contains more yellow light than the spiral branches and their condensations, which are intensely blue; this is in good accordance with the fact that the nucleus has a greater effective wave-length, and belongs to a more advanced spectral class, respectively, than the nebula in its entirety.

¹ J. E. Keeler, "Photographs of Nebulae and Clusters," *Publications of the Lick Observatory*, **8**, 1908.

² *Op. cit.*, First, Second, and Third Papers.

³ "Preliminary Results on the Color of Nebulae," *Communications from the Mount Wilson Solar Observatory to the National Academy of Sciences*, No. 36, 1916; see also *Annual Report of the Director of the Mount Wilson Observatory for the Year 1916*, pp. 248-49.

The plate of this object obtained on May 17 was so strongly blackened and consequently the grating-spectra were so difficult to discern that we have thought we ought not to use it, being so decidedly inferior to the preceding plate, for an accurate determination of the effective wave-length. Measurements made by us on this plate give an effective wave-length, corresponding to the mean of the two given, which confirms Fath's result that the spectrum is of the solar type.

W.H. I.84=N.G.C. 4725

The plate, including this and the following object, was taken for purposes of stellar statistics; hence the grating-spectra of the two nebulae are not sufficiently exposed. The measurements are rather discordant, yet they deserve to have some weight. We obtained on an average $\lambda_{\text{eff}} = 430.4 \mu\mu$. According to Fath,¹ the spectrum is of solar type (G0). Our λ_{eff} value corresponds to a spectral type intermediate between G and K.

M 64=N.G.C. 4826

The measurements of the grating-spectra of this nebula show a greater mutual agreement than those of the spectra of the preceding objects, and $\lambda_{\text{eff}} = 433.8 \mu\mu$ was obtained. Fath² finds that the color-curve is similar to that of a solar-type star, but his plate contains a very weak spectrogram. Max Wolf³ has found that the spectrum is of pronounced G-type (identical with that of the Andromeda nebula). To what extent the contradiction between these investigations and our determination of λ_{eff} , corresponding to the K-type, can be explained from the vagueness which impairs our measurements, we hope, later on, when we have had the opportunity of photographing this object with longer exposure than the one used, to be able to decide.

¹ "The Spectra of Spiral Nebulae" (Second Paper), *Mt. Wilson Contr.*, No. 49, 1911; *Astrophysical Journal*, 33, 58, 1911.

² *Ibid.* (Third Paper), *Mt. Wilson Contr.*, No. 67, 1913; *Astrophysical Journal*, 37, 198, 1913.

³ "Über die Spektren einiger Spiralnebel," *Sitzungsberichte der Heidelberger Akad. d. Wiss., Abth. A*, Jahrg. 1912, 15 Abhandlung.

M₃ = N.G.C. 5272

A determination of the total effective wave-length was not possible for this object, owing to the fact that its considerable extent prevented the central image and the grating-spectra from being quite clearly separated. Besides, the images dissolved into a number of condensations. One of the strongest of these was near the center of the cluster. As grating-spectra of this condensation could be identified, we measured its effective wave-length and obtained $\lambda_{\text{eff}} = 425.1 \mu\mu$. A number of small condensations and accumulations of stars were also measured in this object and gave effective wave-lengths between 424 and $436 \mu\mu$. As, however, there was some doubt as to the identification of the grating-spectra of these condensations, we will not attach any importance to these later measurements. Fath¹ has found that the integrated spectrum of M₃ lies between A and G, and Hertzsprung² has by spectral-photometric measurements shown that the distribution of energy in its integrated spectrum is very nearly like that of a typical F-star. The value found by us for the effective wave-length for the strongest condensation corresponds more to the G than to the F type. Judging from several circumstances, we find that the λ_{eff} should, however, for the cluster in its entirety turn out somewhat lower.

M 51 = N.G.C. 5194

The grating-spectra were fairly well exposed, yet there arose some difficulty at the measuring, because one of them was close to the central image of a condensation in the spiral branches, from which, however, it could be distinguished after a certain amount of practice. Our measurements are probably accurate, giving an average $\lambda_{\text{eff}} = 430.7 \mu\mu$. It was only with the greatest difficulty that Fath³ determined the spectral type for this nebula. A plate exposed for nearly 30 hours gave a spectrum whose color-curve was similar to that of a K-type star and with the lines G and H present.

¹ "The Spectra of Spiral Nebulae" (Second Paper), *Mt. Wilson Contr.*, No. 49, 1911; *Astrophysical Journal*, 33, 58, 1911.

² "Comparison between the Distribution of Energy in the Spectrum of the Integrated Light of the Globular Cluster Messier 3 and of Neighboring Stars," *Astrophysical Journal*, 41, 10, 1915.

³ *Op. cit.*, First and Third Papers.

Wolf,¹ on the contrary, obtained on a plate exposed for 31 hours a spectrum on the whole identical with that of the Andromeda nebula or of the type G. Our value for the λ_{eff} corresponds to a spectral type intermediate between G and K. A star involved in the nebula² ($\alpha = 13^{\text{h}}25^{\text{m}}6$, $\delta = 47^{\circ}42'$) was measured and gave $\lambda_{\text{eff}} = 418.0 \mu\mu$ (type A5).

W.H. I.186=N.G.C. 5195

This object, which forms a secondary nucleus in M 51, situated at the end of one of its spiral branches, showed on our plate a starlike central image with quite distinct grating-spectra, which enabled us to determine the effective wave-length with great accuracy. We obtained $\lambda_{\text{eff}} = 426.3 \mu\mu$. The spectrum of this object has not been examined. With the aid of a yellow-color filter and isochromatic plates Seares³ has examined the color of M 51 and N.G.C. 5195 and has found that the central parts of the two objects are much stronger in yellow light than in blue, and that they consequently belong to a more advanced spectral type than the exterior parts which are intensely blue.

M 57=N.G.C. 6720

The grating-spectra are vague and rather difficult to measure, owing to the considerable extent of the object. The measurements gave $\lambda_{\text{eff}} = 394 \mu\mu$. This result implies that our grating-spectra are in the main formed by the group of lines $\lambda 397$, $\lambda 389$, and $\lambda 387$, of which especially the first and the third have great intensity.⁴ The central star in the ring nebula gave a considerably lower effective wave-length,⁵ but, as its grating spectra could not be

¹ *Op. cit.*, p. 6.

² See G. W. Ritchey, "On Some Methods and Results in Direct Photography with the 60-inch Reflecting Telescope of the Mount Wilson Solar Observatory," *Mt. Wilson Contr.*, No. 47; *Astrophysical Journal*, 32, 26, 1910, Plate XV, where the star is at a distance of 22.5 mm from the nucleus.

³ *Loc. cit.*

⁴ See, on this subject, Max Wolf, "Der Ringnebel und der Dumbbell nebel," *Sitzungsber. d. Heidelberger Akad. d. Wissenschaft*, Abth. A, Jahrg. 1915, 1 Abhandlung.

⁵ See *Annual Report of the Director of the Mount Wilson Solar Observatory for the Year 1916*, p. 249.

identified with perfect certainty, we will not give here the results of those measurements.

M 53 = N.G.C. 5024

The plate was under-exposed. The extremely vague measurements, for which a slightly magnifying ocular was used on the measuring microscope, gave a mean $\lambda_{\text{eff}} = 420 \mu\mu$, which, in our opinion, ought not to be included in the summary below. Fath¹ has found that this cluster gives a spectrum lying between A and G.

M 5 = N.G.C. 5904

In the measurements we used the weaker ocular above mentioned. The grating-spectra were distinctly separated from the central image and proved to consist of a smooth, blackened surface, measurable with some difficulty. The value obtained here for the effective wave-length is valid for the bulk of the stars of which grating-spectra occur on our plate. We obtained $\lambda_{\text{eff}} = 419 \mu\mu$. Fath² has found the following absorption lines present in the spectrum of M 5: F, H_j, H, K, and a band at $\lambda 419$. He is of the opinion that the integrated spectrum of the brighter stars of this cluster lies between F and G.

We have collected the results of our measurements in Table III. Under the heading of "Spectrum Calculated" we have entered the spectral class calculated from the λ_{eff} with the aid of the following formula, derived from Lindblad's measurements mentioned above:

$$\text{Spectral class} = A_0 + \frac{\lambda_{\text{eff}} - 415}{6}$$

From these preliminary investigations, which we hope later on to have the opportunity of completing and expanding, it appears that the connection, found for fixed stars, between spectral type and effective wave-length also exists between the (integrated) spectrum and the effective wave-length of the spiral nebulae and globular clusters. By using the method suggested by us, it consequently ought to be possible, in proportion as the greater instruments are used for the purpose, to determine with tolerable facility the effective wave-length and thereby the spectral type or color-index or temperature

¹ *Op. cit.*, Second Paper.

² *Op. cit.*, Third Paper.

TABLE III

OBJECT	α_{1900}	δ_{1900}	GALACTIC CO-ORDINATES		MAGNITUDE (HOOKE-SCHIE)	EFFECTIVE WAVE-LENGTH		SPECTRUM TRUM CALCULATED	SPECTRUM TRUM OBSERVED	REMARKS
			Long.	Lat.		According to Landolt	According to Lindblad			
N.G.C. 6720 M 57	18 ^h 49 ^m 58 ^s	+32°54'	30°	+14°	8.9	μ_{44} 394	μ_{44} 394	μ_{44} 394	μ_{44} 394	Ring nebula in Lyra
3034 M 82	9 47 6	70 10	109	42	8.8	414	416	A_0	A_0	Gaseous nebula?
5904 M 5	15 13.5	2 27	333	45	6.7	418.7	419.6	F	F-G	Globular cluster
5024 M 53	13 8.0	18 42	307	79	7.8	42	42	F?	F-G	Globular cluster
5272 M 3	13 37.6	28 53	8	77	6.6	425.3	425.0	F	F	Globular cluster
5195 W.H. I. 186	13 25.8	47 47	68	71	8.6	426.3	426.3	G	G	Spiral nebula. This λ_{eff} -value concerns the nebula in its entirety
4736 M 94	12 46.2	41 40	76	76	7.7	427.3	426.1	G	G	This λ_{eff} -value concerns the central nucleus
						433.0	432.8	K	K	Spiral nebula?
3077 W.H. I. 286	9 55.3	60 13	168	42	10.2	427.4	429.7	G	G	Spiral nebula
4725 W.H. I. 84	12 45.5	26 3	154	83	8.7	432.0	428.7	G	G	Spiral nebula
5194 M 51	13 25.7	47 43	68	71	8.4	431.7	429.7	G	G	Spiral nebula
4826 M 64	12 51.8	22 13	295	84	8.6	433.8	433.9	K	K	Spiral nebula. λ_{eff} from plate taken Feb. 22, 1917
N.G.C. 3031 M 81	9 47.3	+69 32	109	+42	8.0	435.7	435.6	K	K	Spiral nebula. λ_{eff} from plate taken Feb. 16, 1917
						436.3	435.4			

also for a considerable number of small, faint nebulae and globular clusters, which are not accessible for investigations of their spectrum by our present spectral apparatus.

If we assume that the parallax of the spiral nebulae and globular clusters examined lies between the same limits as those derived by H. Shapley¹ for M 13:

$$0.^{\circ}00010 > \pi_{M13} > 0.^{\circ}00001,$$

we find that, provided the value of c derived by P. J. van Rhijn² is right, the change in color-index T , caused by the selective absorption in space, must lie between the limits

$$2^M < \Delta T < 19^M$$

Hence it follows that the spectral type calculated by us should on an average differ from those determined in the usual way, where the spectral lines have been observed, by an interval at least twice as large as A-K. This not being the case, it seems to us that our investigation can be considered as a confirmation of the result found by Shapley³, Hertzsprung⁴ and others, *that no sensible absorption exists in space*.

ASTRONOMICAL OBSERVATORY,
UPSALA
June 1917

¹ "Studies Based on the Colors and Magnitudes in Stellar Clusters," *Mt. Wilson Contr.*, Nos. 115-117, 1915-1916.

² "Derivation of the Change of Color with Distance and Apparent Magnitude," *Dissertation*, Groningen, 1915.

³ *Loc. cit.*

⁴ *Loc. cit.*

A NEW FORM OF SPECTRO-COMPARATOR

By RALPH E. DELURY

By employing a half-silvered surface and two microscopes, it is possible for one to construct a comparator possessing special advantages in the measurements and comparisons of photographs of spectra. The device may be arranged in several ways:

I. The microscopes may be set up with their axes intersecting on either side of the objectives and with the half-silvered surface at the intersection.

II. The microscopes may be set up with the axes of the objectives parallel. One beam of light, after passing through its objective, is turned by reflection through one or two right angles to meet, at the half-silvered surface, the direct or similarly reflected beam from the other objective.

The half-silvered surface transmits and reflects in either case about half of each beam; and the images, side by side or overlapping, may be observed in two directions at right angles to one another.

By employing the arrangement I in such form as shown in the diagram, it is possible to produce, with a minimum of optical surfaces, two sets of images in convenient positions for alternate measurement, the configurations appearing rotated 180 degrees with respect to one another. In the case of spectra, one eyepiece would show "violet right" and the other "violet left." Furthermore, in order to compare personal errors of measurement, two observers could conveniently measure together, one at each eyepiece, viewing each other's settings or making alternate settings. (Such a method of comparison between two observers should prove valuable in such observations as the transits of stars, occultations, etc.) To facilitate such comparisons in the measurements of spectra, the comparator should be made to rotate and should be set up on a narrow table with a seat on each side. To avoid the interference of reflections from the outside surfaces, the silvered surface should lie between two wedges or rectangular prisms of glass.

For arrangement II the Hartmann spectro-comparator¹ may be easily adapted by removing the usual silver mask between the components of the double-prism placed below the eyepiece, half-silvering the face of one of the prisms, and cementing the prisms together again with Canada balsam. With this device the Hartmann comparator possesses all the advantages it ordinarily has, and in addition the following:

1. One double-prism suffices for all comparisons. In the Hartmann instrument various kinds of masks are made between

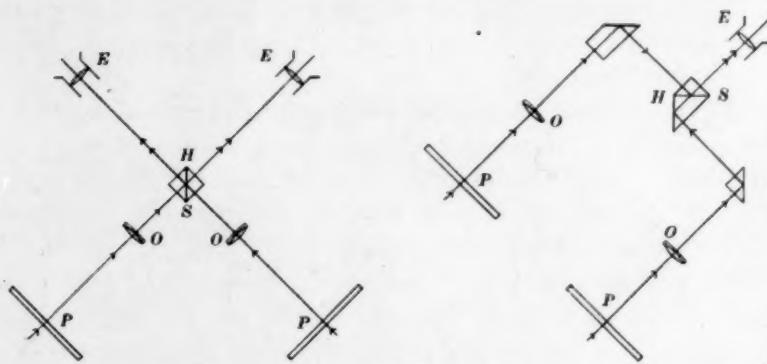


FIG. I

I. New Form of Spectro-comparator

II. Adapted Hartmann Spectro-comparator

E, eyepiece; HS, half-silvered surface; O, objectives; P, photographic plates

the components of the double-prisms, to make possible the comparison of spectra of different configurations; and it is also necessary to focus both images at this mask in order to have the edges of the latter sharp. If the center of the mask be in focus, the outer edges are out of focus (as Hartmann pointed out), and this has a disturbing effect on the observer. Furthermore, a vertical line at this surface is in focus only at its middle and can therefore not be used for setting on spectrum lines in the ordinary way. These difficulties are all overcome by using the half-silvered surface. In this case the images may be brought to focus beyond the double-prism where masks of any desired configuration may be employed,

¹ *Zeitschrift für Instrumentenkunde*, 21, 205-207, 1906; also *Astrophysical Journal*, 24, 285, 1906.

and where adjustable spider lines may be used when desired. Thus comparisons and line bisections may be made at the same time.

2. When the half-silvered surface is used, it is possible to place the images in coincidence in order to detect differences.

3. The new device makes possible the employment of the comparator for measuring photographs of spectra by the promising method suggested by Evershed, namely, that of using, with the negative to be measured, a positive plate made from it, and placed reversed to negative end for end.¹ I have adapted the Hartmann comparator for this purpose and have found it very satisfactory. It overcomes the disadvantages of the method Evershed has employed of sliding positive above negative, in that by the new method the films of positive and negative may be focused in the same plane. (The difficulty of having the films not in the same focus has been practically overcome by Evershed by employing an objective of long focus.) The new method possesses an additional advantage in that the intensity or color of the beams of light from positive and negative may be altered independently, thus making it possible, by matching the intensities of the positive and negative or by increasing the contrast, to measure the displacements of spectral lines of almost any character, even the broad lines in some stellar spectra.

4. By overlapping the spectra no parts of them need be cut out, as is the case in using the arbitrary masks of the Hartmann instrument.

In Table I are given the means of the measurements of displacements (produced mechanically) of 15 lines ($\lambda\lambda$ 4196.599-4291.630, intensities 1-5), of six exposures of the spectrum of the solar limb by: (1) the ordinary method of bisecting with spider line, taking the differences between means of four settings on the middle strip and means of two settings on each of two outside strips of spectrum, each way (violet right and violet left)²; (2) by measuring negative (violet left) with positive of itself (violet right) on the adapted Hartmann comparator, taking differences

¹ *Kodaikanal Observatory Bulletin*, No. 32, 1913.

² *Journal Royal Astronomical Society of Canada*, 5, 398, 1911.

between means of two settings on the middle strip and means of two settings on each of the two outside strips of spectrum, each way (violet left and violet right). A comparison of the results of the two methods shows the practicability of the new device and the lessening (nearly halving) of the probable error of setting obtained by employing the positive-with-negative method.

TABLE I
MEASUREMENTS OF PLATE L701 BY TWO METHODS

	I. BISECTION WITH SPIDER LINE, 1911						Means
	a	b	c	d	e	f	
Mean displacement in mm.....	0.0690	0.0699	0.0702	0.0699	0.0690	0.0686	0.0694
Probable error, single line.....	0.0029	0.0030	0.0027	0.0027	0.0015	0.0029	0.0026
Probable error of mean.....	0.0008	0.0008	0.0007	0.0007	0.0004	0.0008	0.0007
II. POSITIVE-WITH-NEGATIVE, 1917							
	a	b	c	d	e	f	Means
Mean displacement in mm.....	0.0692	0.0700	0.0708	0.0704	0.0690	0.0692	0.0698
Probable error, single line.....	0.0020	0.0014	0.0015	0.0012	0.0015	0.0014	0.0015
Probable error of mean.....	0.0005	0.0004	0.0004	0.0003	0.0004	0.0004	0.0004

When the adapted Hartmann comparator is used, remeasurements of solar rotation plates show good agreement with my earlier measures by the method of bisection of lines; and the comparisons promise to throw light on the systematic differences in the measurements of the same lines on the same plates by different observers. For example, the measurements of 19 lines, λ 5506.095-5688.436, Plate L845(1), are:

Bisection of lines by spider thread:

De Lury, mean of 9 measures, 1911-1916, is..... 1.618 km/sec.
Plaskett, mean of 2 measures, 1911, is..... 1.695 km/sec.

Positive-with-negative:

Evershed, 1 measure, 1916, is..... 1.636 km/sec.
De Lury, mean of 3 measures, 1917, is..... 1.619 km/sec.

To test the applicability of the new form of comparator to the determination of stellar radial velocities, I have measured plates of β Geminorum with positives of solar standard plates (or vice versa),

selecting plates which had been previously measured¹ (by J. S. Plaskett) in testing the Hartmann spectro-comparator. Instead of groups of comparison lines and groups of stellar and solar lines being aligned in turn, as in the Hartmann method, these groups are brought into coincidence in turn, positive fitting into negative in a most satisfying manner. In all cases two settings were made on solar and stellar coincidences; and one on each of the two strips of comparison spectrum at each region. The plates were then reversed and measured in the same way. Less than a minute at each region each way was the average time expended. The measurements are given in Table II, and the degree of reliability of the measures may be judged by the following measurements of a zero displacement (22 regions) of solar standard 1462 with positive plates A and B from it:

1462 with positive A, -0.0010 mm

1462 with positive B, -0.0007 mm; 0.0000 mm; 0.0016 mm; 0.0004 mm
Mean, 0.0006 mm; or 0.04 km/sec.

Probable error of single measure, ± 0.24 km/sec.; probable error of mean, ± 0.14 km/sec.

(It is to be expected that the errors can be lessened considerably by adopting Evershed's method of using negative violet left and positive violet right, or vice versa, even though the measurement is in this case confined to a single comparison line and a single solar and stellar line—a method which has the obvious advantage of yielding information concerning the behavior of the individual lines.)

From Table II it will be seen that repeated measurements are close in the case of Plates 1527 positive A and 1520 negative, and much closer for 1527 negative and 1520 positive A. For the former the probable error of a single measure is ± 0.43 km/sec.; and for the mean, ± 0.22 km/sec.; while for the latter the probable error of a single measure is 0.07 km/sec.; and for the mean, 0.03 km/sec. This latter is a degree of accuracy seldom attained, I believe, for stellar plates of the low dispersion used, by either the bisection method or the Hartmann method for so few settings and

¹ *Report of the Chief Astronomer*, 1909, pp. 183 f.

regions. Accuracy of setting is dependent to a great degree on the careful balancing of the intensities of positive and negative when making the settings or when printing out the positive. The agreement between the overlapping-positive-with-negative measurements (De Lury) and the aligning-negative-with-negative measurements (Plaskett) is only fair; and both measures seem greatly superior to the agreement of the solar standards or of the stellar plates.

TABLE II

MEASUREMENTS OF β GEMINORUM BY TWO METHODS

(De Lury using positive-with-negative; Plaskett using the Hartmann method, negative-with-negative.)

β GEM. PLATE	SUN PLATE	No. OF REGIONS	D (DE LURY, 1917)			P (PLASKETT, 1909)			DIFFERENCE P-D km/sec.
			Measured Velocity km/sec.	Reduced Velocity km/sec.	Mean Velocity km/sec.	Measured Velocity km/sec.	Reduced Velocity km/sec.	Mean Velocity km/sec.	
1373-....	1360+A	20	24.80	2.88	2.88	24.78	2.86	2.86	-0.02
1373-....	1462+A	22	24.88	3.08	.....	24.23	2.43	.....	.....
1373-....	1462+B	22	25.01	3.21	.....	24.31	2.51	.....	.....
1373-....	1462+C	22	24.84	3.04	3.11	.....	.....	2.47	-0.64
1373-....	1520+A	11	23.74	1.84	.....	25.01	3.11	.....	.....
1373-....	1520+A	11	23.30	1.40	.....	.....	.....	.....	.....
1373-....	1520+A	11	23.94	2.04	1.76	.....	.....	3.11	+1.35
1472-....	1520+A	11	31.12	1.88	1.88	31.27	2.03	2.03	+0.15
1527+A....	1520-	11	25.56	0.85	.....	27.03	2.32	.....	.....
1527+A....	1520-	11	26.15	1.44	.....	.....	.....	.....	.....
1527+A....	1520-	11	27.12	2.41	.....	.....	.....	.....	.....
1527+A....	1520-	11	25.76	1.05	1.44	.....	.....	.....	.....
1527-....	1520+A	11	26.31	1.60	.....	.....	.....	.....	.....
1527-....	1520+A	11	26.13	1.42	.....	.....	.....	.....	.....
1527-....	1520+A	11	26.09	1.38	.....	.....	.....	.....	.....
1527-....	1520+A	11	26.12	1.41	1.45	.....	.....	2.32	+0.87
					2.22			2.56	+0.34

The main advantages of the new form of comparator are:

1. A minimum of optical surfaces are used.
2. Images may be brought into coincidence; and thus the Evershed positive-with-negative method of measuring spectra may be employed without the disadvantages found in using the positive over the negative and with the added advantage that the intensities of positive and negative may be altered independently and contrast gained by using colored filters.

3. Two sets of images are produced and may be observed in two different eyepieces, the instrument being in fact a *double* comparator.

4. In measuring spectra, the instrument may be used in the ordinary way of bisecting the lines with a spider thread; or it may be used as a comparator for overlapping or aligning, for which masks for various configuration may be readily interchanged.

SOLAR PHYSICS DIVISION
DOMINION OBSERVATORY, OTTAWA
April 1917

ON THE SPIRAL OF OBSCURATION IN THE STELLAR UNIVERSE

A REPLY TO MR. F. H. SEARES

By H. H. TURNER

Mr. Seares has made a valuable determination of the galactic condensation¹ from part of the material collected by me from counts of the zones of the *Astrographic Catalogue*. There are several points in his paper on which I offer comments, but it is natural to take first the most important one in which I find myself directly at variance with him. He states that "the deviations of the observed densities [Table VI of his paper] . . . are not in agreement with the spiral of obscuration derived by Turner from the same data." This statement I challenge directly; and I submit the following figures taken straight from his Table VI. The equation suggested for the spiral is

$$\alpha + 3.66 \delta = 247^{\circ}$$

The values of α calculated from this equation for the declinations of Table VI are shown in the second line below:

Dec . . .	+ 62°	+ 28°	+ 17°	+ 9°	- 1°	- 17°	- 32°	- 41°	- 42°
α . . .	+ 20°	+ 145°	+ 185°	+ 214°	+ 257°	+ 309°	+ 4°	+ 37°	+ 41°
Used . . .	1 ^h	9 ^h	13 ^h	15 ^h	17 ^h	21 ^h	1 ^h	3 ^h	3 ^h
Error . . .	- 5°	- 10°	+ 10°	+ 11°	+ 4°	+ 6°	+ 11°	+ 8°	+ 4°

Since Table VI only gives results for the odd hours 1^h, 3^h, 5^h, etc., we cannot use these exact values of α but must take the nearest odd hours, as shown in the third line of the table. We now simply rearrange Table VI by commencing the circuits of R.A. with the hours above indicated. Further, we do not want the numbers of Table VI themselves, but merely the differences between the first and last column of each declination. (See table of differences on p. 227.) Simple sums are given at the foot. It will be seen that those from (11) to (19) are all positive but one, the mean of them being +31; those from (21) to (9) are, with one excep-

¹ *Mt. Wilson Contr.* No. 135; *Astrophysical Journal*, 46, 117, 1917.

tion, negative, the mean being -35 . Analyzing the twelve terms harmonically we get

$$-13 \sin \theta - 33 \cos \theta = -35 \cos (\theta - 20^\circ),$$

so that the maximum *obscuration* occurs when $\theta = +20^\circ$, about an hour later than is given by the formula

$$a + 3.66 \delta = 247^\circ.$$

[In the foregoing work the Melbourne zone has been omitted for reasons indicated in *Monthly Notices*, 77, 224, 1917; the spiral no longer follows the foregoing equation south of $\delta = -55^\circ$.]

DIFFERENCES OF TABLE VI RE-ARRANGED IN SPIRAL FORM

(1)	(3)	(5)	(7)	(9)	(11)	(13)	(15)	(17)	(19)	(21)	(23)
- 3	- 15	- 5	+ 7	- 1	- 6	+ 9	+ 2	+ 2	+ 8	- 16	- 11
+ 1	- 5	+ 7	- 7	- 16	- 15	+ 1	+ 1	- 14	- 34	- 24	+ 23
+ 8	- 9	- 12	- 9	+ 8	+ 27	+ 6	+ 5	- 5	- 6	- 23	- 19
+ 4	- 7	- 13	- 10	- 5	+ 21	+ 22	+ 11	- 13	+ 22	- 3	+ 11
- 2	- 4	+ 2	- 2	+ 8	+ 12	- 2	+ 11	+ 6	- 3	- 5	+ 5
+ 3	+ 3	+ 5	+ 10	- 28	- 9	- 1	+ 13	+ 1	+ 9	- 16	+ 14
- 3	- 1	+ 3	- 8	+ 1	- 11	- 4	+ 2	- 1	+ 5	+ 9	0
- 19	- 2	- 12	- 26	+ 7	- 1	+ 14	+ 12	+ 3	+ 6	- 8	- 12
0	- 9	- 4	- 8	+ 5	+ 7	+ 13	+ 10	+ 14	+ 6	- 2	- 5
- 11	- 49	- 29	- 53	- 21	+ 25	+ 53	+ 67	- 7	+ 13	- 88	+ 6

Adopting the crude supposition that the differences are directly proportional to differences of magnitude, since the latter are

$$+62^\circ \quad +28^\circ \quad +17^\circ \quad +9^\circ \quad -1^\circ \quad -17^\circ \quad -32^\circ \quad -41^\circ \quad -42^\circ \\ 2.6 \quad 3.3 \quad 2.3 \quad 2.0 \quad 1.2 \quad 3.4 \quad 2.5 \quad 2.5 \quad 0.9,$$

the sum of which is 20.7 , then the coefficient 35 of the foregoing harmonic represents $0.35/20.7 = 0.017$ per magnitude. This would be denoted 1.7 in such a series as that for R' in Table V of *Monthly Notices*, 77, 225, 1917, and is distinctly small; but it is of the right order of magnitude and its smallness is, at any rate, partly due to the crude manner of deducing it by throwing together material from widely different parts of the sky.

It is accordingly submitted that Mr. Seares's Table VI, so far from being "not in agreement with the spiral of obscuration," gives very good evidence in support of it; the small discordances

being what we might expect when a portion of the whole material is separately discussed.

I will now add one or two remarks on other points. In his opening sentences Mr. Seares represents it as my "purpose to show that important conclusions may be derived simply by counting the stars within each interval of brightness, even when the scale of luminosity is arbitrary." This is a fair statement of what the purpose has become in the course of time; but I am anxious that the *original* purpose of these papers should not be forgotten. I urged that counts of the kind mentioned would be the simplest way of co-ordinating the various scales of the *Astrographic Catalogue* one with another, and I hope that the advantages and facility of such comparisons have been amply demonstrated. The method was rejected at the last meeting of the Permanent Committee in favor of a series of special investigations on sample plates. There can be no question of the value of such a piece of work, which Professor E. C. Pickering has done much to facilitate, but it will be costly in time and labor; and it is not free from pitfalls, as those who have tried it know from their experience. The pitfalls are being discovered and avoided and the labor is being faced, so that we shall ultimately have a really satisfactory scale to which all the Astrographic magnitudes may be referred. But meanwhile we can by these counts co-ordinate them very closely with a single, though arbitrary, scale, which will never be work thrown away.

The physical results, for which the counts have lately become useful, were not part of the first purpose, except that *incidentally* the first few counts seemed to throw doubt on the progression of the galactic condensation and it was interesting to follow up this clue. It led directly to the recognition of some other phenomenon (now regarded as the spiral of obscuration) which seemed to be more marked than the galactic phenomenon; but ultimately (as noted by Mr. Seares) the progression of the galactic condensation was recognized and even crudely determined. That a better determination has not hitherto been given is due simply to the fact that more material is being accumulated—there is a goodly stock already in hand—and it was thought better to defer the definitive discussion. Mr. Seares's paper is however most welcome; it seems to show that

Kapteyn's determination is so good that it may profitably be adopted (as at any rate a first approximation) to clear the results from the galactic condensation before presentation. Up to now they have not been so cleared, at first because the progression of the condensation seemed to be discredited, and later because it had not been sufficiently well determined for use.

Finally, I demur to the following statement of Mr. Seares: "The question under consideration is really that of the uniformity of the stellar distribution in galactic longitude." I have stated several times that the spiral has no relation to the Galaxy. Hence galactic longitude *alone* is inappropriate for the discussion; we must include at the same time galactic latitude, just as we should have to use *both* ecliptic longitude and latitude, or *both* of any series of co-ordinates except those which are definitely related to the spiral itself. Only when we recognize the spiral in our co-ordinates is it possible to conduct the discussion in one co-ordinate; it is because we recognize the Galaxy in our co-ordinates that we can discuss the galactic condensation in terms of galactic latitude only. How much importance Mr. Seares attaches to the foregoing statement I scarcely know; but he makes it as though to clarify the discussion, whereas I am concerned to point out that it obscures it.

UNIVERSITY OBSERVATORY

OXFORD

July 1917

COMMENTS ON MR. SEARES'S REJOINDER

(Added September 13, 1917)

This discussion was opened by Mr. Seares in the September number of this *Journal*. He courteously sent me his paper in manuscript, and on receipt of it (July 14) I replied at once in the hope that my reply might appear with his paper. But apparently this was not possible. The reply was returned to me (received September 12) with a rejoinder, and with the intimation that copies of both were in the hands of the editor of this *Journal* and would appear in October or (more probably) November if I cabled to that effect. After reading the rejoinder I sent the cable. But

as there is a certain lack of symmetry in the conduct of a discussion which leaves the last word always on one side, I send these few lines in the hope that they too may be added.

Mr. Seares changes his ground in the rejoinder. His former statement was that certain deviations "were *not in agreement* with the spiral of obscuration." For simplicity of reference let us substitute the statement that certain quantities, $-3, -2, -1, +1, +2, +3, +5, +6, +7$, are "not in agreement" with a positive mean value, the responsibility for italics and for substitution being entirely mine. My reply was to add them up and show that the sum is $+18$. Mr. Seares replies by asking, "Is not something more than a positive sum required for the substantiation of a positive mean value?" The italics and translation are again mine. I use them to make clear the change of ground and to simplify the reply. To the former charge of want of agreement the reply is already made. To this quite different question my reply is: Certainly something more is required. With these particular numbers we can only *suggest* a positive value, we cannot *substantiate* it. For that we require more material, which I am doing my best to accumulate. Already there is a great deal in print, of which, for excellent reasons, Mr. Seares has so far been unable to take account. But the existence or non-existence of the spiral (represented above by the positive mean value $+2$) will ultimately be settled by the whole material, not by my views or Mr. Seares's views of the significance of a limited sample.

It is true that the sample examined contains a very large number of stars and cannot be disregarded. Had it been in contradiction with the main thesis, the objection would have been serious. But there is a distinction between "not in agreement with" and "being sufficient to substantiate." The former phrase suggests a tendency to substantiate the contrary, and against it I have made my protest; whereas, that we have as yet sufficient evidence to substantiate the spiral I have never claimed deliberately. If there be some careless phrase which seemed to claim it, may I not rather be judged by my acts than by my words—my diligence in collecting more material and in pleading that others will do the same?

One word more—in considering some of the points raised by Mr. Seares it is important to remember that he is not raising them for the first time. He suggests, for instance, a possible seasonal effect on the observations. This point was considered in the second paper of the series (dealing with the Bordeaux observations);¹ and more recently the evidence for and against a seasonal effect has been given in detail. Again, as regards the accordance of different zones, details have been collected more than once. Had such important points been overlooked the criticisms would have had more point. But Mr. Seares has, as a matter of fact, adduced very little that is really new. He has given a welcome precision to the progression in galactic condensation; but the crude estimates already given in the papers were of the right order of magnitude, and a definitive discussion would naturally have followed in due course when additional materials now available had been put in shape. Perhaps we may profitably postpone the remainder of this discussion till then?

H. H. TURNER

¹ *Monthly Notices*, 72, 464, 1912.

THE SPIRAL OF OBSCURATION¹
COMMENTS ON PROFESSOR TURNER'S REPLY
By FREDERICK H. SEARES

Professor Turner discusses² numerically the data in Table VI of *Mount Wilson Contribution* No. 135³ and concludes that they give very good evidence in support of the spiral of obscuration. He demonstrates the substantial agreement of the progressive change in the sums of quantities derived from this table, when appropriately rearranged,⁴ with the varying ratio of faint stars to bright stars defined by the spiral. But is not something more than accordance in the sums required for the substantiation of the spiral? Such an agreement might appear when the differences in each line but one of Professor Turner's table were all zero, although the evidence obviously would not then support the spiral, but indicate instead a local phenomenon affecting only a single zone of declination. Evidently the number of zones agreeing with the spiral must also be considered, and unless these are numerous the support of individual favorable cases will be accepted with caution.

Examining Professor Turner's table, we find that the clustering of signs is to be traced mainly to the similar variations affecting the zones at $+17^\circ$, -41° , and -42° , although part of it is attributable to the circumstance that the algebraic sums of the quantities in each line are not zero. Adding a constant to each line to make the sums zero and transferring the results for $+17^\circ$ to the bottom, we have Table I, whose sums display the same progressive change as was found by Professor Turner.

For the first six zones the clustering is no longer conspicuous. It is pronounced, however, for the last three, whose minima agree satisfactorily with the obscured region of the spiral. Two zones ($+62^\circ$, -1°) among the first six are also in agreement, although the amplitude is not much larger than the accidental errors. The

¹ *Contributions from the Mount Wilson Solar Observatory*, No. 139.

² *Astrophysical Journal*, 46, 226, 1917. ³ *Ibid.*, 46, 117, 1917.

⁴ See last line of his table on p. 227 and the related discussion.

sequence of signs for $+9^\circ$ suggests an agreement, but the beginning of the series corresponds to a nodal point rather than a minimum. The remaining three cases ($+28^\circ$, -17° , -32°) are unfavorable. The zone at -65° is not included, as it has already been rejected by Professor Turner as discordant. Noting that the two Cape zones have essentially the same declination and count, therefore, as one, we find no excess of favorable cases, even when the last three zones are included.

TABLE I
(Unit = 0.01 in Logarithm)

Zone	First Hour	(1)	(3)	(5)	(7)	(9)	(11)	(13)	(15)	(17)	(19)	(21)	(23)
$+62^\circ$	1	-1	-13	-3	+9	+1	-4	+11	+4	+4	+10	-14	-9
$+28$	9	+8	+2	+14	0	-9	-8	+8	+8	-7	-27	-17	+30
$+9$	15	+1	-10	-16	-13	-8	+18	+19	+8	-16	+19	-6	+8
-1	17	-4	-6	0	-4	+6	+10	-4	+9	+4	-5	-7	+3
-17	21	+3	+3	+5	+10	-28	-9	-1	+13	+1	+9	-16	+14
-32	1	-2	0	+4	-7	+2	-10	-3	+3	0	+6	+10	+1
-41	3	-16	+1	-9	-23	+10	+2	+17	+15	+6	+9	-5	-9
-42	3	-2	-11	-6	-10	+3	+5	+11	+8	+12	+4	-4	-7
$+17$	13	+10	-7	-10	-7	+10	+29	+8	+7	-3	-4	-21	-17
Sum first six.....		+5	-24	+4	-5	-36	-3	+30	+45	-14	+12	-50	+47
Sum last three.....		-8	-17	-25	-40	+23	+36	+36	+30	+15	+9	-30	-33
Sum all zones.....		-3	-41	-21	-45	-13	+33	+66	+75	+1	+21	-80	+14
Mean lat., first six....		39°	38°	39°	39°	37°	32°	30°	26°	26°	31°	32°	35°
Mean lat., last three...		64	43	20	4	18	27	24	12	18	33	56	71

A certain amount of progressive fluctuation is to be expected, however. Seasonal factors, for example, are almost certain to influence the results; and even when their phases are distributed at random from zone to zone, the number of cases agreeing with an assigned distribution closely enough to be accepted as favorable to that distribution will be considerable. In the present instance it does not appear that this number is large enough to establish a relation between the observed distribution and the spiral of obscuration. These details may be verified by an inspection of the curves in the right half of Fig. 2 of *Mount Wilson Contribution* No. 135.

Examining now the question quantitatively, we form the sums for each column of the first six zones and find an oscillation of sign

that appears to be wholly fortuitous, whence we conclude that the fluctuation noted by Professor Turner is caused by the pronounced variation affecting the zones at -41° , -42° , and $+17^\circ$. In other words, the irregular distribution in these two regions affects appreciably the mean for all the data, and it is this dominating influence of the Cape and Bordeaux results that appears in Professor Turner's figures; but, since the total number of cases of agreement is not greater than might have been expected because of inherent uncertainties, I see no reason for modifying the judgment previously expressed.

Irregularities in the stellar distribution undoubtedly exist, and eventually it may appear that those remaining after eliminating the effect of the galactic condensation possess a systematic character; but I should hesitate to believe that at present we have any reliable indication of such a phenomenon. As far as the data under discussion are concerned, the spiral

$$a - 2.24 \delta = 206^\circ$$

seems to represent them much better than the one proposed by Professor Turner. The matter is immediately tested by drawing a line across the right half of Fig. 2 of my original paper in such a way as to intersect the $+62^\circ$ axis at $a = 23^h$, and the -65° axis at $a = 4^h$. This will then represent the line of greatest obscuration, and inspection shows that in no case will the agreement with the minima of the individual curves be less satisfactory than before, while for $+28^\circ$, -32° , and -65° there will be an appreciable improvement. But at the present moment, in view of the undoubtedly presence of seasonal influence and other systematic errors in the Astrographic counts, I should attach no significance to this circumstance.

Finally, it is important to note that an appropriate modification of the galactic condensation adopted for the faint stars will remove entirely the progressive variation which arises from the preponderating influence of the zones at -41° , -42° , and $+17^\circ$. Let us examine the mean latitudes in the last two lines of the table. For the first six zones these are sensibly the same for all the columns,

but for the last three zones they show a marked variation. Now the quantities in the body of the table are differences of the form¹

$$\delta = \log \frac{D_F}{D_B} - \log \frac{N_F}{N_B},$$

the first term involving the observed value of the ratio of faint stars to bright, while the second includes the value of this ratio calculated from the mean densities in Table III, *Mount Wilson Contribution* No. 135. A change in the adopted galactic condensation of faint stars relative to bright stars will modify the second term, but for a specified galactic latitude the change will be constant and the *relative* values of δ for a series of equal latitudes will remain unchanged. Since the mean latitudes for the first six zones are nearly equal, the sequence of the sums of the tabular quantities for these zones will not be appreciably affected by a change in the condensation.

On the other hand, the three zones which show a marked fluctuation in δ also show a wide range in the mean latitudes. Positive values of δ in these zones correspond in general to small galactic latitudes, and negative values to large latitudes. Now suppose the tabulated mean density for the faint stars to be slightly increased in the lower latitudes. This will increase N_F and reduce the positive values of δ to zero. A similar but opposite change in N_F for the higher latitudes will neutralize the negative values of δ .

I have previously mentioned² the uncertainty affecting the determination of the galactic condensation from the Astrographic data, and a reference to the lower curve in Fig. 1 of *Mount Wilson Contribution* No. 135, which illustrates the difficulty experienced in drawing some of the curves, will indicate whence this uncertainty arises. The modification necessary to eliminate entirely the progressive variation in the sums of δ for all the zones is well within this uncertainty, and for this reason the mean densities derived in *Mount Wilson Contribution* No. 135 may be accepted for the present.

These conclusions are also in harmony with other circumstances. For example, it is a contention of this discussion that the spiral of

¹ See equation (1) of *Mt. Wilson Contr.*, No. 135.

² *Mt. Wilson Contr.*, No. 135, p. 13; *Astrophysical Journal*, 46, 129, 1917.

obscuration, for the most part, is only the increasing galactic condensation which appears with increasing limiting magnitude exhibited under another form, and that the spiral disappears when the data are freed from the effects of the condensation. Treated by themselves, the Cape results for -41° indicate a very high relative value of the condensation, much higher than the mean for all the data. When corrected with the aid of tables of mean distribution, traces of the galactic concentration (or of the spiral) will remain, and this is just what we find for the zone in question.

Professor Turner has commented on the magnitude of the condensation for this zone,¹ and it is of interest to note that, with the exception of the zone at $+62^{\circ}$, the other values of the condensation coefficients given by him² are all similarly related to the systematic variations shown in the right half of Fig. 2, *Mount Wilson Contribution* No. 135. Thus the Bordeaux and Algiers coefficients ($+17^{\circ}$, -1°) are also large, and the corresponding curves, like that for the Cape, have been counted as cases favorable to the spiral, while the small values for Oxford and Perth ($+28^{\circ}$, -32°) correspond to unfavorable cases.

The remaining comments to be made on Professor Turner's reply are altogether minor in character. He refers to my use of only a part of the material collected by him. To avoid misunderstanding it may be well to repeat that some of his published data are not in a form suitable for the investigation undertaken in *Mount Wilson Contribution* No. 135. All that could be used were included in the discussion.

I think that we are entirely in agreement as to the importance of the counts he has collected. They undoubtedly admit of a close co-ordination of the scales of the various Astrographic zones, as Professor Turner himself has shown by the comparisons that he has made with the scale of Chapman and Melotte. The regularity of increase in stellar density with decreasing galactic latitude, which appears even when the counts are restricted to comparatively small areas, is an impressive phenomenon and an excellent indication of the value of density as a measure of stellar brightness.

¹ *Monthly Notices*, 75, 608, 1915.

² *Ibid.*

The meaning of the sentence from my article quoted by Professor Turner in the last paragraph of his reply would have been clearer had the wording been different. The implication was that we wish information as to the uniformity of distribution after the galactic condensation has been removed. By looking for irregularities along parallels of latitude, the effect of the condensation will not enter, and we may feel certain that any irregularities thus discovered will not be the consequence of residual errors in the adopted values of the condensation. But to trace the course of any irregularity, galactic latitude, the second co-ordinate, naturally requires consideration, as Professor Turner suggests.

MOUNT WILSON SOLAR OBSERVATORY

August 22, 1917

REVIEWS

Collected Papers on Spectroscopy. By G. D. LIVEING and SIR J. DEWAR. Cambridge University Press, 1915. Pp. xv+556. With 35 plates, 18 maps, and numerous diagrams. 30s.

This collection of "Papers on Spectroscopy" has a value entirely its own, given to it partly by the high standing of its joint authors, partly by the inherent importance of the results set forth. The work of Liveing and Dewar, covering the last quarter of the nineteenth century, is well known. It has long illustrated the effectiveness of co-operation when the talents combined are really complementary. In this particular case we see two eminent scholars, one mainly a chemist, the other mainly a physicist, joining forces upon a problem which is really physico-chemical.

The principal issue in spectroscopy has shifted greatly from the time when Newton employed the solar spectrum for a study of color, or when Young and Fresnel measured diffraction spectra in order to test certain theories of light, or when Bunsen used the prism chiefly for the discovery of new chemical elements, or when the constitution of various celestial objects commanded the attention of Sir William Huggins.

Current literature indicates that spectroscopic endeavor is now largely directed along electro-optical lines, including spectral series and the criteria which they furnish for theories of atomic structure. To say that all the beautiful advances which have recently been made in the manufacture of fine dispersion-pieces are merely ancillary to this more fundamental problem does not in any way detract from their importance.

Between these earlier and later purposes fall the labors of these two Cambridge scholars, who early set themselves the task of finding what they could concerning the physical constitution of laboratory sources—the mechanics of the arc, spark, and flame. It was well recognized even at the commencement of their work that a single substance may present several different spectra. Accordingly their search resolved itself into finding a one-to-one correspondence between a series of spectra and a series of physical states in the source. The difficulty of the quest lay partly in the fact that many of these spectra had never been described, but more largely in the fact that it is tremendously difficult—practically

impossible—to depict the physical conditions which are encountered in almost any of the sources.

To be sure, one can give the voltage across an arc, either on open or closed circuit; the mean amperage also; the temperature of the solid electrode; the end-products of the chemical action. And it must be confessed that the profound knowledge of chemistry brought to bear by these two authors fitted them in an eminent degree for "guessing" at the chemical processes going on inside these electrical sources and flames. But how far all this is from knowing the instantaneous electrical and magnetic fields, the mechanical motions, the pressure, the density, the chemical constitution, the actual structure of the tiny mechanism which emits light!

Bohr's theory offers us a most interesting atomic skeleton; but, as Professor Millikan has pointed out (*Science*, **45**, 330), it does not explain the mechanics of radiation. No one recognizes how far we are from the goal more clearly than these two authors themselves, who in a late paper frankly confess that we are still "wholly ignorant of the mechanism by which the gas is lighted up."

Nevertheless, one must admire the vigor of their pursuit; for these papers are filled with keen observations and cleverly devised experiments. Witness their early attempts to discover series-relations, their observations on lines which are now designated as "enhanced," their early distinction between the nitrocarbon and hydrocarbon bands, their resolution of the magnesium fluting (λ 5007) into lines, their suspicion that the edge of this fluting did not coincide with the green nebular line, their recognition of asymmetric reversals, the effect of nitrogen and hydrogen atmospheres in altering the relative intensity of certain lines, and a host of other phenomena.

Their paper on the spectrum of magnesium was, at the time of its appearance, almost a treatise on spectroscopy. Paper No. 57, dealing with the absorption spectrum of oxygen, led to the important conclusion that there was no resemblance between the absorption in the compounds of oxygen and the absorption in the element itself—a marked extension of the work of Janssen and his colleagues in the Royal Stables at Meudon.

Among the important contributions in the collection must be mentioned those papers which describe the recently discovered gases of the earth's atmosphere, those which detail the isolation of these elements, and those which give the preparation of spectrum-tubes by use of liquid air and liquid hydrogen.

The methods employed traverse the entire history of the science from liquid hydrogen back to the days of Rutherford gratings and arcs operated by 25 Grove cells. On page 283, where the Rowland grating is compared with that of Rutherford, one's curiosity is aroused by the remark that "the Rutherford grating is in some respects the better of the two." Again, in Paper 43, "On the Use of the Collimating Eyepiece in Spectroscopy," one wonders how the so-called Littrow form of spectroscope (invented, as Littrow himself says, by Duboscq) ever came to be described under the title of an "eyepiece."

It goes without saying that in all their pages there is a spirit of careful scholarship which no camouflage can ever imitate. There are those who think that the appreciation of such work dates from August 1914; but it is really very old. Sir David Brewster well understood the value of such science more than half a century ago. It was during the Crimean War that he wrote his *Memoirs of Sir Isaac Newton*, in the dedication of which he says: "It is from the trenches of science alone that war can be successfully waged; and it is in its patronage and liberal endowment that nations will find their best and cheapest defence."

H. C.